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SUPERSONIC AXISYMMETRIC NOZZLE DESIGN BY MASS FLOW TECHNIQUES UTILIZING A DIGITAL COMPUTER

By

W. C. Moger and D. B. Ramsay

Engineering Support Facility

ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER

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a subsidiary of Sverdrup and Parcel, Inc.

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FOREWORD

The authors wish to acknowledge the assistance of James C. Sivells and Clark R. Fitch of the Hypersonic Branch, von Kármán Gas Dynamics Facility, ARO, Inc., who initiated the problem, gave valuable suggestions, and supplied the comparison of theoretical and computed results (Fig. 5) in this report.

ABSTRACT

This report presents a method to design the inviscid wall contour of a supersonic, axisymmetric nozzle producing uniform parallel flow at the exit. The calculation methods used are restricted to a perfect gas. The axis velocity distribution must be specified. A complete flow pattern within the nozzle is computed by the method of characteristics beginning at Mach 1.0 on the axis and extending to the region of uniform parallel flow at the exit. The wall points are calculated by means of a mass integration technique. The methods of calculation included have been programmed in Fortran II language, and a complete listing of the program is given in Appendix I.

PUBLICATION REVIEW

This report has been reviewed and publication is approved.

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CONTENTS

ILLUSTRATIONS

NOMENCLATURE

M	Mass flow
m_o	Initial mass integration value
P	$\dfrac{\sin\theta \sin\alpha \, dy}{\sin(\theta \pm \alpha)\, y}$
Q	$\cot \alpha / W$
r	Radius
s	Distance along a characteristic
V	Velocity
W	Velocity/limiting velocity (V/V_{max})
X	Physical abscissa
Y	Physical ordinate
α	Mach angle ($\sin\alpha = 1.0$/Mach number)
γ	Ratio of specific heats
η	Inflection angle
θ	Flow angle (with respect to axis)
ρ	Density
ψ	Prandtl-Meyer angle

SUBSCRIPTS

1	Refers to right-running characteristic
2	Refers to left-running characteristic
a	Origin of right-running characteristic
b	Origin of left-running characteristic
c	Computed point
B, C	End points on line BC
N	Normal Component
p	Point on line BC
q	Point on line CD
t	Total (stagnation condition)

1.0 INTRODUCTION

This report presents a method to design the inviscid wall contour of a supersonic, axisymmetric nozzle producing uniform parallel flow at the exit. The calculation methods used are restricted to a perfect gas. The axis velocity distribution must be specified.

A complete flow pattern within the nozzle is computed by the method of characteristics beginning at Mach 1.0 on the axis and extending to the region of uniform parallel flow at the exit. The wall points are calculated by means of a mass integration technique.

The methods of calculation included in this report have been programmed in Fortran II language, and a complete listing of the program is given in Appendix I. This program has been run on the IBM 7074 computer at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), to obtain the results to be presented.

2.0 SCOPE OF CALCULATIONS

For the purpose of calculations the flow in the nozzle is arbitrarily divided into three distinct regions as shown in Fig. 1.

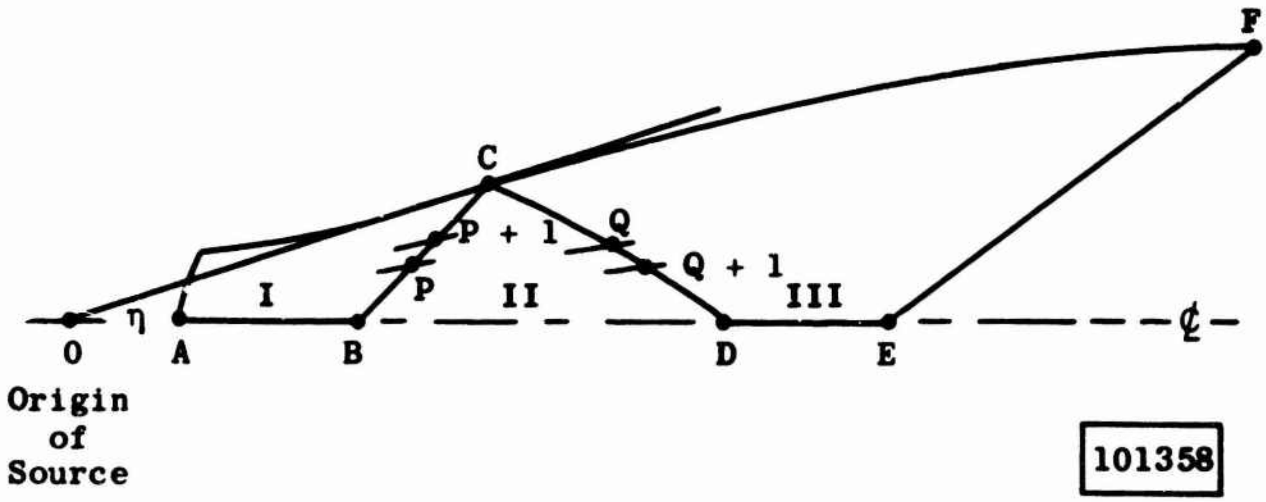


Fig. 1 Major Nozzle Divisions

Manuscript received May 1964.

2.1 THROAT REGION

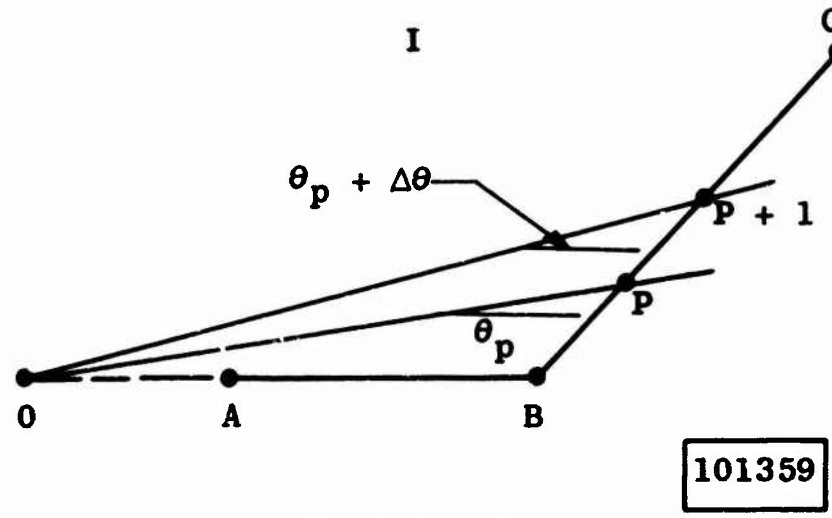


Fig. 2 Throat Flow

In calculating flow within the throat region, points A and B of Fig. 2 are given points.

The velocity distribution on AB is given either by an equation or as a series of discrete points. The flow angle at point C, the inflection point, is also an input value. Knowing this angle and the velocity at point B, a left-running characteristic BC (the upstream boundary of the source flow region) can be established using the source flow relation

$$\psi_p = \psi_B + 2\theta_p$$

where the subscript p refers to a point on the characteristic line BC. Line BC is then divided into an arbitrary number of segments having an equal $\Delta\theta$ between successive points. These are initial points for right-running characteristics from line BC. The mass flow in the nozzle is found by integrating along BC using the technique outlined in Section 2.4.

An arbitrary number of points are specified as the origin points for the left-running characteristics beginning on the axis. Characteristic lines are calculated until a field point is computed from the last known wall point. As the last characteristic point lies beyond the wall, a mass integration technique is applied to find the wall point location on the characteristic line.

2.2 SOURCE FLOW REGION

The area enclosed by BCD in Fig. 1 consists entirely of source flow, and no characteristic solutions are computed.

2.3 DOWNSTREAM REGION

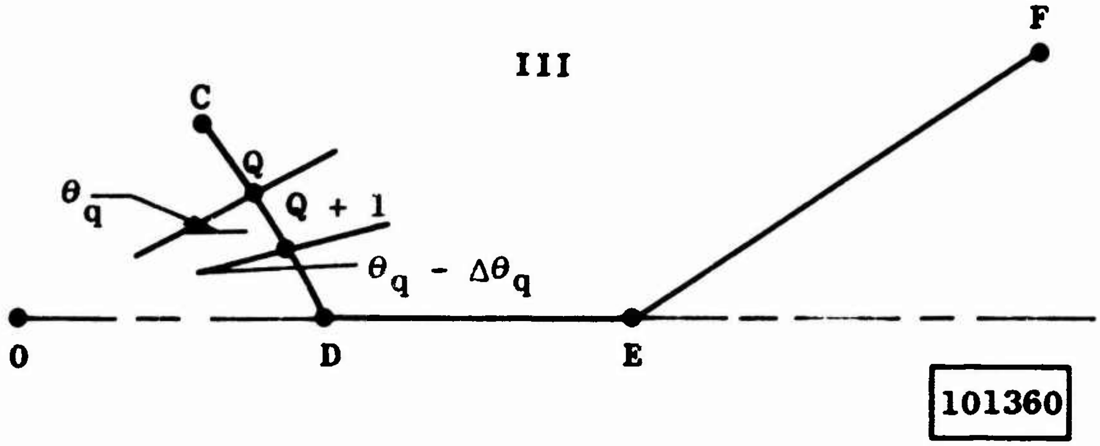


Fig. 3 Downstream Flow

Line CD is a right-running characteristic line on the downstream boundary of the source flow region. This characteristic is calculated in a manner similar to line BC in the throat region. Here the relation used to establish this line is

$$\psi_q = \psi_c + 2(\eta - \theta_q)$$

In a manner analogous to that used in defining the axis line AB, it is necessary to designate points D and E and to specify an axial velocity distribution to establish line DE. Also similar to the procedure used for Region I, line DE is divided into an arbitrary number of segments. The axis points are the origins of right-running characteristics.

Successive right-running characteristics originating from line DE are computed, and wall points are found by mass integration as in the throat region.

Line EF in Fig. 3 is a left-running characteristic consisting of uniform parallel flow at the desired design exit Mach number. Line EF is a straight line divided into an arbitrary number of equal intervals for origin points to right-running characteristics. The mass integration along characteristics from line EF is handled in a different manner than integrations beginning on the axis. Here the calculations are performed with an initial mass integration value of

$$m_o = \left(\frac{r}{r_{exit}}\right)^2 \text{ X Total Mass}$$

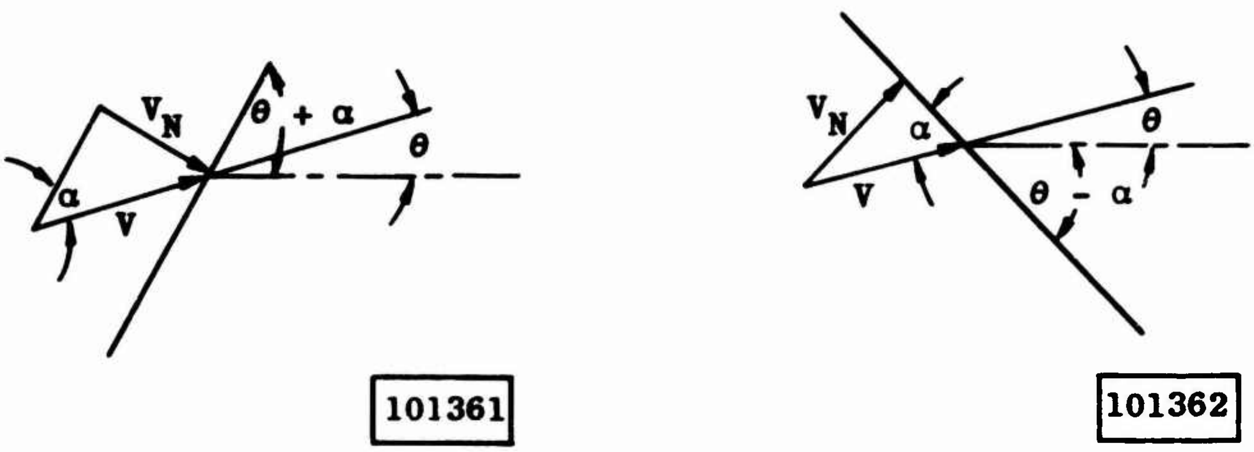
2.4 MASS INTEGRATION TECHNIQUE

The differential equation governing mass flow at a point on a characteristic line is

$$dM = 2\pi \cdot r \cdot V_N \cdot \rho \cdot ds \tag{1}$$

The normal component of velocity at a point on either a right-running or a left-running characteristic is

$$V_N = V \cdot \sin \alpha$$



a. Left-Running

b. Right-Running

Fig. 4 Characteristics

Let $\rho = \left(\frac{\rho}{\rho_t}\right) \cdot \rho_t$ where $\left(\frac{\rho}{\rho_t}\right) = (1 - W^2)^{\frac{1}{\gamma - 1}}$

and $V = \frac{V}{V_{max}} \cdot V_{max} = W \cdot V_{max}$. Now Eq. (1) may be expressed as

$$dM = 2\pi \cdot r \cdot W \cdot V_{max} \cdot \sin \alpha \cdot (1 - W^2)^{\frac{1}{\gamma - 1}} \cdot \rho_t \cdot ds \tag{2}$$

For a given nozzle condition, the factor $2\pi \cdot V_{max} \cdot \rho_t$ is constant. By letting $m = \frac{M}{2\pi \cdot V_{max} \cdot \rho_t}$ and substituting in Eq. (2), one obtains the nondimensionalized mass differential equation

$$dm = r \cdot W \cdot (1 - W^2)^{\frac{1}{\gamma - 1}} \cdot \sin \alpha \cdot ds \tag{3}$$

By defining

$$r \cdot W \cdot (1 - W^2)^{\frac{1}{\gamma - 1}} \cdot \sin \alpha \equiv f(s)$$

Eq. (3) can be simplified to

$$dm = f(s)\, ds \tag{4}$$

To calculate the nondimensional flow in the nozzle, the following technique is used.

In the throat region, the left-running characteristic defining the origin of the source flow region, Region II in Fig. 1, is known from the axis to the wall. Equation (4) is integrated as follows:

For each point on the line BC, the value f(s) is calculated. The distance (s) from the axis to any point is the sum of the straight line segments from point to point.

The mass integral is computed by analytically evaluating a parabolic fit through each three consecutive points and summing the integral values. The limit of integration of each integral is from the first to the second point.

Computations for mass in the downstream region, Region III in Fig. 1, is carried out in a similar form except that integration is along the right-running characteristic line CD.

2.5 LOCATING WALL POINTS ON A CHARACTERISTIC

The final point calculated on each characteristic line will be beyond the corresponding wall point for that line. Hence, if the nondimensionalized mass flow is integrated to the final point it will exceed the nozzle mass flow. To find the unknown wall point, the sum of the mass flow from point to point is calculated until a point on the characteristic line is reached where the line mass integral exceeds the known nozzle mass flow. An iteration technique is applied to find the unknown wall point. The values of the wall point are calculated by linear interpolation of the known end point values.

3.0 RESULTS

A comparison of theoretical results and the characteristic solution in the transonic region is shown in Fig. 5. The points shown were calculated by the program included in this report.

One important factor in the proper use of this program is the selection of the initial points of the characteristic line beginning on the axis. The spacing will depend upon the axis velocity distribution. It has been found that a value of $1.5 \lessapprox p \lessapprox 2.0$ will result in a good spacing in the throat where

X_1 = Abscissa at Mach number 1.0
X_2 = Abscissa at the beginning of source flow region
N = Nth point $1 \leq N \leq M$
M = Total number of points on the throat axis
X = Abscissa corresponding to the Nth point

$$\frac{X - X_1}{X_2 - X_1} = \left(\frac{N - 1}{M - 1}\right)^p$$

A prior computer program was written to obtain the inviscid wall contours by means of an extrapolation technique based on the starting known wall point and extending this along the wall streamline by extrapolation of the flow direction. The technique was found to be unsatisfactory since errors tended to be propagated from point to point. It was also found that the network size greatly affected the accuracy in locating the wall. With the mass flow integration technique used, no propagated error occurs since the calculation of each wall point is based on a single characteristic line. The total number of points needed in the characteristic field to obtain satisfactory inviscid wall contours was considerably less than required with the streamline extrapolation technique.

4.0 CONCLUSION

A comparison was made of the flow field in the throat region calculated by the techniques in this report to analytical results of other sources. Excellent agreement of results was found between the methods (see Fig. 5).

With this program an inviscid wall contour can be designed with an initial wall point on the left-running characteristic corresponding to Mach 1.0 on the axis to an exit having uniform parallel flow. It must be kept in mind that the methods applied hold for a perfect gas and that the axis velocity distribution must be specified.

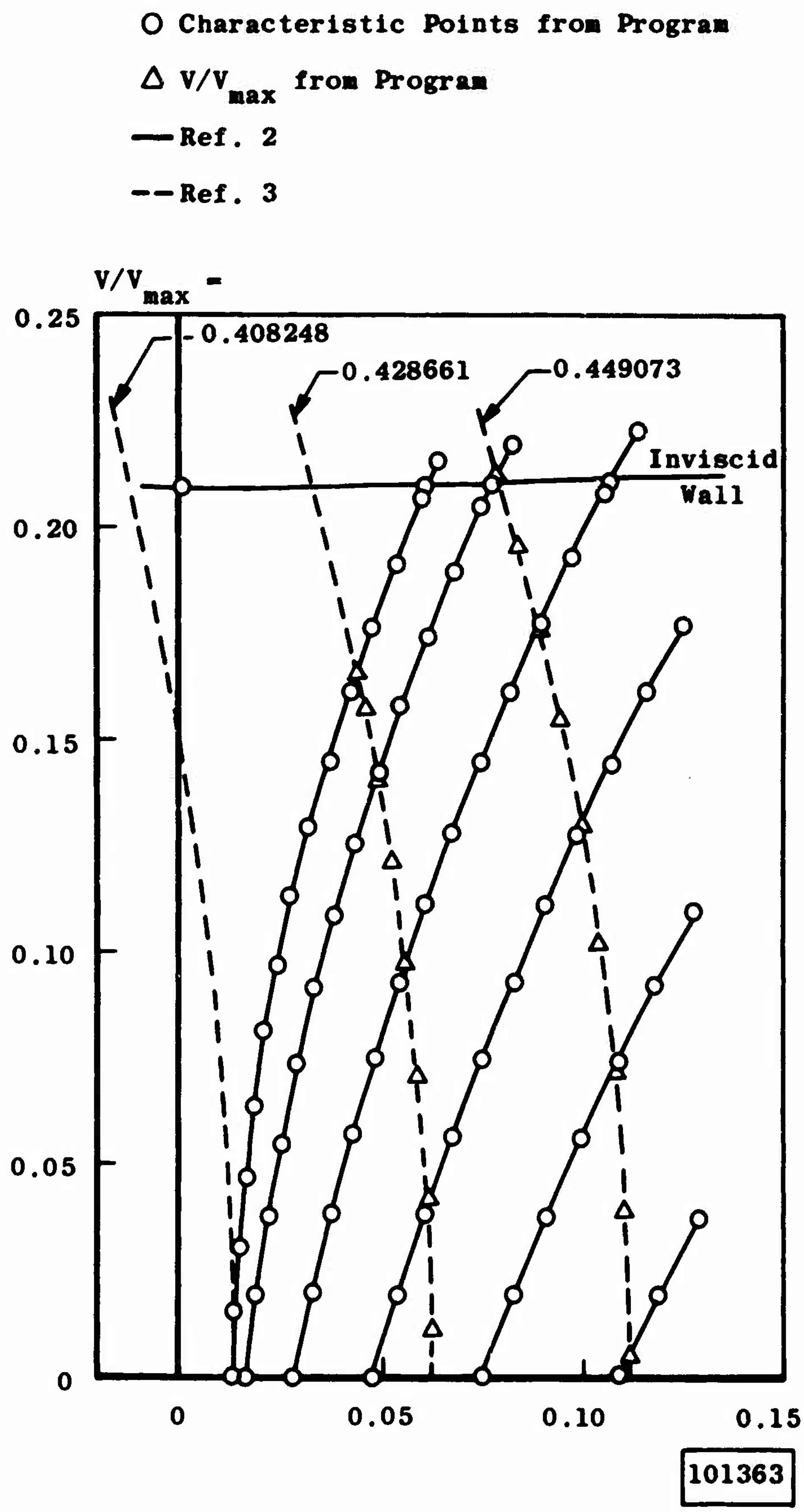


Fig. 5 Comparison of Theoretical and Computed Results

REFERENCES

1. Shapiro, Ascher H. The Dynamics and Thermodynamics of Compressible Fluid Flow. The Ronald Press Company, New York, 1953. (2 volumes)
2. Sauer, R. "General Characteristics of the Flow Through Nozzles at Near Critical Speeds." NACA-TM-1147, June 1947.
3. Oswatitsch, K. and Rothstein, W. "Flow Pattern in a Converging Diverging Nozzle". NACA-TM-1215, March 1949.

APPENDIX I

COMPUTER PROGRAM FOR NOZZLE CONTOUR

The program presented here is based on the methods outlined in the preceding sections. As previously pointed out, there is a difference in the manner of computing the throat and downstream regions, and they may be computed either separately or together.

In either case, a complete set of input data must be prepared for the region under consideration. However, if the downstream region is computed immediately after the throat region, the X-location of the inflection point need not be specified as it is calculated as the wall point on line BC in Fig. 1.

Care must be exercised in specifying the distance between points on the axis to ensure that the characteristic points to be computed will be properly spaced. If axis points A1 and B1 in Fig. 6 are chosen judiciously, A2 will be computed in a manner to make it almost equidistant from its parent points. This effect will be propagated throughout the field.

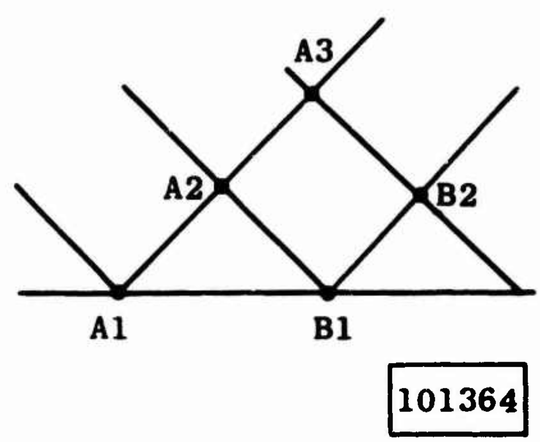


Fig. 6 Axis Distribution

The number of points on an initial characteristic line in either region should be chosen such that the dimension size in the program is not exceeded as points are added to successive characteristic lines.

NOMENCLATURE OF PROGRAM

A	Parameters associated with right-running characteristics
B	Parameters associated with left-running characteristics
C	Coefficients of polynomial describing the axis
S	Characteristic arc length
FS	Integrand value used in mass integration technique
AXIS	Refers to parameters located on the centerline
BEGIN	Refers to parameters on the initially calculated characteristic, i.e., line BC in the throat region and CD in the downstream region.
FINAL	Refers to the parameters calculated at points along line EF.
WALL	Refers to the values calculated at the wall points found by the method described in Section 2.5.
IEND	Control to end program or to calculate
M	Number of points taken on BEGIN line, BC or CD
N	Number of axis points
IX	Control dependent on method used to set up axis
	IX = -1 if discrete X-coordinates are to be read in preceded by the corresponding values of V/V_{max}; coefficients, C, not used.
	IX = 0 if discrete X-coordinates are to be read in and V/V_{max} is to be calculated from the coefficients, C.
	IX = +1 if axis points are to be computed. Coefficients are to be read in.
IWOT	Control on amount of calculated points to be written out.
	IWOT = 0 writes out wall, axis, and first and last characteristics
	IWOT ≠ 0 writes out all calculated points
IP	Indicates which region is to be computed
	IP = 0 for Region I
	IP ≠ 0 for Region III
NP	Number of points to be taken on line EF

GAM	Ratio of specific heats
ETA	Angle at inflection point, point C, in degrees
XC	X-coordinate at point C
X1 & X2	V/V_{max} is a polynomial dependent on an X_R relative to source flow such that

$$V/V_{max} = W = f(\bar{X})$$

where

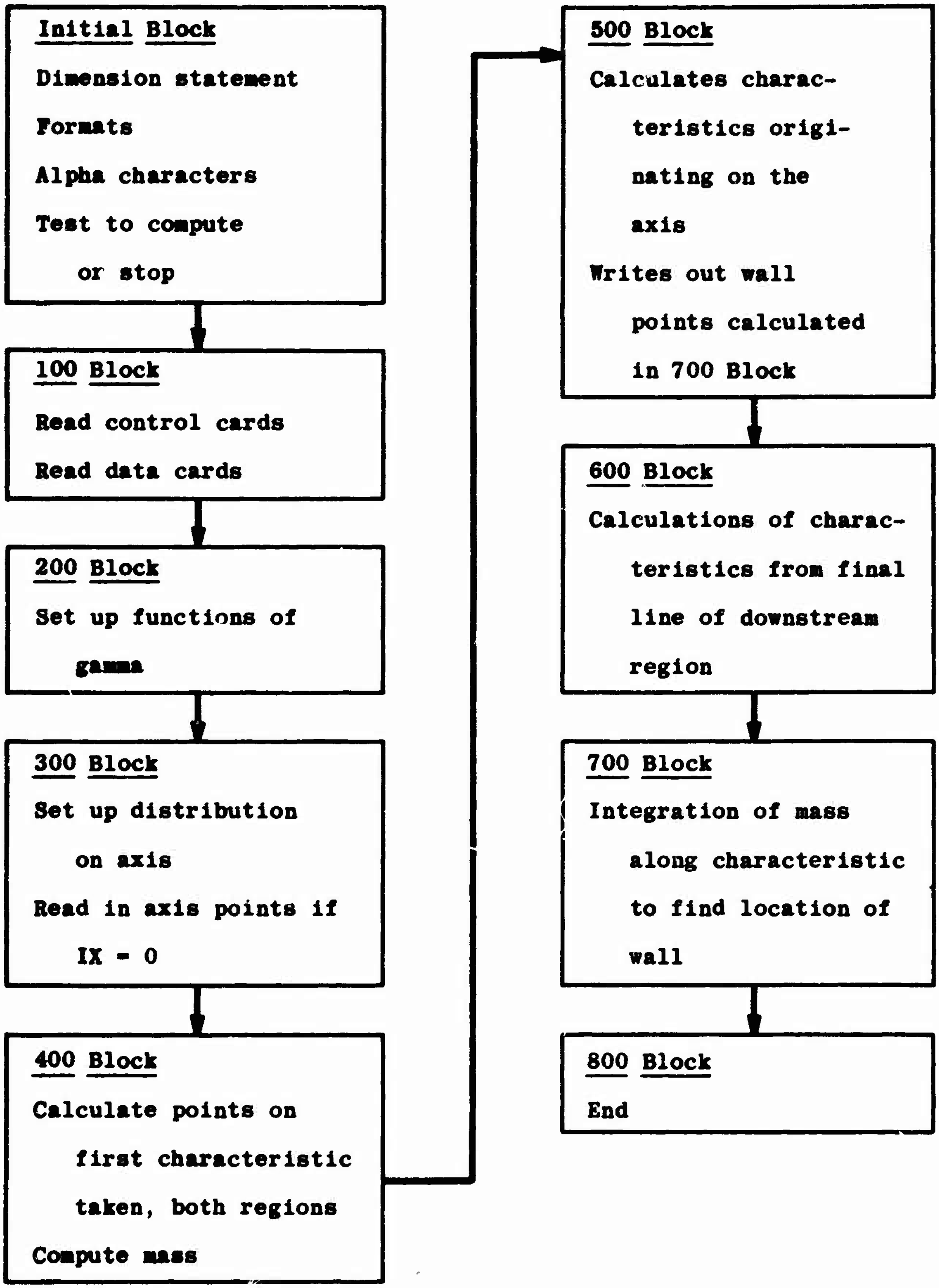
$$\bar{X} = \frac{X_R - X1}{X2 - X1}$$

P	Governs distribution on axis. P = 1 for linear distribution. P > 1 packs axis points toward low end of axis.
C	Constants used in defining the velocity ratio along the axis in terms of V/V_{max}.
XHI	Maximum X-coordinate on the axis, point B or E
XLO	Minimum X-coordinate on the axis, point A or D
AXIS(1, N)	Axis coordinates to be read in when $IX \neq 0$
AXIS(3, N)	V/V_{max} corresponding to axis points to be read in when $IX = -1$

Subscripts (on A, B, AXIS, BEGIN, FINAL, and WALL)

First subscript (1-6)
1 = X-coordinate
2 = Y-coordinate
3 = V/V_{max}
4 = Mach angle
5 = Flow angle
6 = Mach number

Second subscript (1-100) designates point number.


Initial Block
Dimension statement
Formats
Alpha characters
Test to compute
or stop
100 Block
Read control cards
Read data cards
200 Block
Set up functions of
gamma
300 Block
Set up distribution
on axis
Read in axis points if
IX = 0
400 Block
Calculate points on
first characteristic
taken, both regions
Compute mass
500 Block
Calculates charac-
teristics origi-
nating on the
axis
Writes out wall
points calculated
in 700 Block
600 Block
Calculations of charac-
teristics from final
line of downstream
region
700 Block
Integration of mass
along characteristic
to find location of
wall
800 Block
End

INPUT DATA AND SAMPLE VALUES

(Input values of IEND, M, N, IX, IWOT, IP, NP, GAM, ETA, XA, X1, X2, P, C, XHI, XLD, and AXIS discussed in Nomenclature of Program.)

Sample input used for design criteria of Mach 8, nozzle half angle, ETA = 12 deg.

Throat region (Region 1):

IEND = 1 (to proceed with calculations)

M = 15 (15 right-running characteristics from line BC)

N = 20 (20 axis points right-running characteristics)

IX = 1 (to calculate distribution along axis)

IWOT = 1 (to write out all characteristics)

IP = 0 (to calculate in the throat region)

NP = 0 (to calculate in the throat region)

GAM = 1.4

ETA = 12 deg

XC = 0.0 (not used for throat calculations)

X1 = 0.4727 (discussed in Nomenclature of Program)

X2 = 1.91607 (discussed in Nomenclature of Program)

P = 2.0 (square distribution on axis)

C(1) = 0.408248247

C(2) = 0.551273121

C(3) = 0.010438091

C(4) = -0.369697773

C(5) = 0.229213428

C(6) = -0.042703583

XHI = 1.91607

XLO = 0.4727

Downstream Region (Region III):

IEND = 1

M = 40

N = 6

IX = 1

IWOT = 1

IP = 1

NP = 35

GAM = 1.4

ETA = 12 deg

XC = 0.0 (calculated in throat region and not necessary to read in)

X1 = 13.015491

X2 = 15.211972

P = 1.0

C(1) = 0.961279408

C(2) = 0.005421945

C(3) = 0.005421945

C(4) = 0.001807315

C(5) = 0.0

C(6) = 0.0

XHI = 15.211972

XLO = 13.015491

IEND = 0 (to end program).

```
C         05314  MAIN PROGRAM AXI-SYMMETRIC SUPERSONIC NOZZLE
C         PROGRAMMED BY WC MOGER AND DB RAMSAY
C         COMPUTATION BASED ON MASS FLOW INTEGRATION BY PARABOLIC FIT
C
C
          DIMENSION A(6,100),B(6,100), C(6) ,D(10),FS(100),S(100)
          DIMENSION AXIS(6,100),BEGIN(6,100),FINAL(6,100),WALL(6,100)
          EQUIVALENCE (BEGIN(1),FINAL(1))
    1     FORMAT (9H FN 05314)
    2 0   FORMAT (I1,78H
    2 1                                    )
    3     FORMAT (16I5)
    4     FORMAT (6E12.0)
    5     FORMAT (/////10X,5HINPUT///5X,
      1   45HNUMBER OF POINTS ON FIRST CHARACTERISTIC (M)=I3//
      2   5X,29HNUMBER OF POINTS ON AXIS (N)=I3//5X,6HGAMMA=F7.4//
      3   5X,23HINFLECTION ANGLE (ETA)=F7.3,2X,7HDEGREES//
      4   5X,36HCOORDINATE OF INFLECTION POINT (XC)=F9.5//
      5   5X,38HFACTORS IN V/VMAX TO DETERMINE X (X1)=F9.5//38X
      6   5H(X2)=F9.5//5X,38HPOWER GOVERNING AXIS DISTRIBUTION (P)=F8.5
      7   //5X,31HCOEFFICIENTS IN TERMS OF V/VMAX//10X,5HC(1)=1PE13.7
      8   //10X,5HC(2)=1PE13.7//10X,5HC(3)=1PE13.7//10X,5HC(4)=1PE13.7
      9   //10X,5HC(5)=1PE13.7//10X,5HC(6)=1PE13.7)
    7 0   FORMAT (1H1,10X,A5//10X,5HPOINT,8X,1HX,14X,1HY,12X,6HV/VMAX
    7 1   6X,12HMACH ANG.(D),3X,12HFLOW ANG.(D),4X8HMACH NO.//10(10X
    7 2   ,I3,2X,1P6E15.7/)/)
    8 0   FORMAT(1H110XA5,I3//10X,5HPOINT,8X,1HX,14X,1HY,12X,6HV/VMAX
      1   6X,12HMACH ANG.(D),3X,12HFLOW ANG.(D),4X8HMACH NO.//)
    9     FORMAT (10X,I3,2X,1P6E15.7)
   10     FORMAT (10HOFELD LINE,I3,6H POINT,I3)
   11     FORMAT (10X,I3,2X,1P6E15.7,2X,6H(MASS))
C
C
   15     TYPE 1
          WRITE OUTPUT TAPE 24,1
          XXC=1.0
          IFIRS = 6669798283
          IAXIS = 61876982
          ICHAR = 63686179
          IWALL = 86617373
          CONV = 57.29578
   17     READ 2,IEND
          IF(IEND)100,804,100
  100     DO 101 J=1,600
          AXIS(J)=0.0
  101     A(J)=0.0
          SENSE LIGHT 0
          WRITE OUTPUT TAPE 24,2,IEND
          READ 3,M,N,IX,IWOT,IP,NP
          READ 4,GAM,ETA,XC,X1,X2,P
          READ 4,C
          WRITE OUTPUT TAPE 24,5,M,N,GAM,ETA,XC,X1,X2,P,(C(J),J=1,6)
          ETA=ETA/CONV
          IF(XC)200,103,200
  103     XC=XXC
```

```
C
C         200 SERIES SETS UP FUNCTIONS OF GAMMA USED THROUGHOUT
C                        THE PROGRAM
C
  200     G9 = 2.0/(GAM-1.0)
          G8 = 1.0/G9
          G7 = GAM+1.0
          G6 = GAM-1.0
          G5 = G6/G7
          G4 = SQRTF(G5)
          G2 = 1.0/G4
          G1 = 1.0/G6
          EXP   = 0.5/G5
          CONST = (0.5*G7)**EXP
          EXP   = -EXP
          NN=1
C
C         300 SERIES SETS UP DISTRIBUTION ON THE AXIS
C
  300     IF(IX)310,305,301
  301     READ 4,XHI,XLO
          DX=XHI-XLO
          FN = FLOATF(N-1)
          DO 304 J=1,N
          IF(IP)303,302,303
  302     K=J
          GO TO 304
  303     K=N-J+1
  304     AXIS(1,K)=DX*(FLOATF(N-J)/FN)**P+XLO
          GO TO 306
  310     READ 4,(AXIS(3,J),J=1,N)
  305     READ 4,(AXIS(1,J),J=1,N)
  306     DO 307 J=1,N
          X=AXIS(1,J)
          X=(X-X1)/(X2-X1)
          IF(IX)311,312,312
  311     W=AXIS(3,J)
          GO TO 313
  312     W=C(1)+X*(C(2)+X*(C(3)+X*(C(4)+X*(C(5)+X*C(6)))))
          AXIS(3,J)=W
  313     WW         = W*W
          XM         = SQRTF(G9*WW/(1.0-WW))
          AXIS(6,J) = XM
          S(J)=1.0/XM
          AXIS(4,J)=ASINF(S(J))*CONV
  307     CONTINUE
          WRITE OUTPUT TAPE 24,7,IAXIS,(K,(AXIS(J,K),J=1,6),K=1,N)
          CM=AXIS(6,N)
          DO 308 J=1,N
  308     AXIS(4,J)=S(J)
          IF(IP)309,400,309
  309     XM=COSRF(ETA)/XC
          XM=XM*XM
          XM=FMA(XM,GAM)
          AXIS(6)=XM
```

```
C
C        400 SERIES SETS UP FIRST CHARACTERISTIC AND
C                    COMPUTES MASS
C
  400    PO=G2*ATANF(SQRTF(G5*(AXIS(6)*AXIS(6)-1.0)))
       1 -1.5707963+ASINF(1.0/AXIS(6))
         EM = ETA/FLOATF(M-1)
         DO 401 J=1,M
         T  = FLOATF(J-1)*EM
         IF(IP) 403, 402, 403
  402    XM=FMV(PO+T+T,GAM)
         GO TO  404
  403    T=ETA-T
  409    XM=FMV(PO+2.0*FLOATF(J-1)*EM,GAM)
  404    W=XM*XM*G8
         R = SQRTF(1.0/(CONST*XM*((1.0+G8*XM*XM)**EXP)))
         IF(IP)406,405,406
  405    K=J
         GO TO 407
  406    K=M-J+1
  407    A(1,K)=R*COSRF(T)
         A(2,K)=R*SINRF(T)
         A(3,K)=SQRTF(W/(1.0+W))
         A(4,K)=1.0/XM
         A(5,K)=T
  401    A(6,K)=XM
  410    IEND = 6*M
         DO 411 J=1,IEND
  411    BEGIN(J) = A(J)
         BEGIN(2,1)=0.0
         BEGIN(5,1)=0.0
  420    DO 421 J=1,6
  421    WALL(J) = A(J,M)
         S(1)=0.0
  430    DO 431 J=2,M
         W    = A(3,J)
         DX=A(1,J)-A(1,J-1)
         DY=A(2,J)-A(2,J-1)
         S(J)=S(J-1)+SQRTF(DX*DX+DY*DY)
  431    FS(J)=A(2,J)*W*A(4,J)*(1.0-W*W)**G1
  440    LAST = M - 2
         SUM  = 0.0
         DO 441 J=1,LAST
         K=J
         CALL PARAB(S(K),FS(K),D(1))
  441    SUM=POLNT(D(1),S(K),S(K+1))+SUM
         SUM=POLNT(D(1),S(LAST+1),S(LAST+2))+SUM
         XMASS = SUM
  460    DO 461 J=1,M
         BEGIN(4,J)=ASINF(BEGIN(4,J))*CONV
  461    BEGIN(5,J) = BEGIN(5,J)*CONV
         WRITE OUTPUT TAPE 24,7,IFIRS ,(K,(BEGIN(J,K),J=1,6),K=1,M)
  470    LAST = M
         LINE = 2
C
```

```
C          500 SERIES COMPUTES CHARACTERISTICS ORIGINATING
C                     ON THE AXIS
C
   500     DO 501 J=1,6
   501     B(J) = AXIS(J,LINE)
   502     DO 506 J=1,LAST
           K = J
           IF(IP)504,503,504
   503     CALL OFELD(A(1,K),B(1,K),B(1,K+1),G9)
           GO TO 505
   504     CALL OFELD(B(1,K),A(1,K),B(1,K+1),G9)
   505     B(6,K+1)=1.0/B(4,K+1)
           IF(SENSE LIGHT 1)507,506
   506     CONTINUE
           GO TO 508
   507     TYPE 10,LINE,J
           LAST = J
           SENSE LIGHT 1
   508     LASTP=LAST+1
           IGO=1
           ME=LINE
           IF(IP)509,700,509
   509     FINAL(6,NN)=0.0
           GO TO 700
   538     IF(N-LINE)539,550,539
   539     LINE=LINE+1
           DO 540 I=1,600
   540     A(I)=B(I)
           GO TO 500
   541     DO 542 J=1,LINE
           WALL(4,J) = ASINF(WALL(4,J))*CONV
   542     WALL(5,J)=WALL(5,J)*CONV
           I=6*LINE
           DO 543 JJ=1,I
   543     B(JJ)=WALL(JJ)
           JJ=LINE
           DO 545 L=1,LINE
           DO 544 I=1,6
   544     WALL(I,L)=B(I,JJ)
   545     JJ=JJ-1
           WRITE OUTPUT TAPE 24,7,IWALL,(K,(WALL(J,K),J=1,6),K=1,LINE)
           XXC=WALL(1,K)
           GO TO 800
   550     IF(IP)600,541,600
C
C          600 SERIES COMPUTES CHARACTERISTICS ORIGINATING ON
C                     THE FINAL LINE OF THE DOWNSTREAM SEGMENT
C
   600     IF(NN-1)603,601,603
   601     NNP=N+1
           W=AXIS(3,N)
           FS(NP)=SQRTF(2.0*XMASS/(W*(1.0-W*W)**G1))
           DELX=FS(NP)*SQRTF(CM*CM-1.0)
           FN=1.0/FLOATF(NP-1)
           DO 602 JJ=1,NP
```

```
          F=FLOATF(JJ-1)*FN
          FINAL(1,JJ)=AXIS(1,N)+F*DELX
          FINAL(2,JJ)=F*FS(NP)
          FINAL(3,JJ)=W
          FINAL(4,JJ)=AXIS(4,N)
          FINAL(5,JJ)=0.0
   602    FINAL(6,JJ)=XMASS*F*F
   603    NN=NN+1
          DO 604 I=1,600
   604    A(I)=B(I)
          DO 606 J=1,600
   606    B(J)=FINAL(J)
          DO 607 J=NN,LAST
          K=J
          CALL OFELD(B(1,K),A(1,K),B(1,K+1),G9)
          B(6,K+1)=1.0/B(4,K+1)
          IF(SENSE LIGHT 1)608,607
   607    CONTINUE
          GO TO 609
   608    TYPE 10,NN,J
          LAST=J
   609    LASTP=LAST+1
          IGO=NN
          ME=NNP
          GO TO 700
   640    NNP=NNP+1
          IF(NN-NP)600,641,600
   641    NL=NNP-1
          DO 642 J=1,NL
          WALL(4,J)=ASINF(WALL(4,J))*CONV
   642    WALL(5,J)=WALL(5,J)*CONV
          WRITE OUTPUT TAPE 24,7,IWALL,(K,(WALL(J,K),J=1,6),K=1,NL)
          GO TO 800
C
C         700 SERIES WRITES OUT CHARACTERISTICS AND INTEGRATES
C                     ALONG CHARACTERISTIC FOR WALL POINT
C
   700    IF(IWOT)701,703,701
   701    WRITE OUTPUT TAPE 24,8,ICHAR,ME
          DO 702 J=IGO,LASTP
          Z = ASINF(B(4,J))*CONV
          T = B(5,J)*CONV
          IF(IGO-J)723,721,723
   721    IF(IP)722,723,722
   722    IF(N-ME)724,723,723
   724    WRITE OUTPUT TAPE 24,11,J,B(1,J),B(2,J),B(3,J),Z,T,B(6,J)
          GO TO 702
   723    WRITE OUTPUT TAPE 24,9,J,B(1,J),B(2,J),B(3,J),Z,T,B(6,J)
   702    CONTINUE
   703    IF(SENSE LIGHT 1)704,705
   704    IF(IP)641,541,641
   705    S(1)=0.0
          DO 706 J=2,LASTP
          W     = B(3,J)
          DX=B(1,J)-B(1,J-1)
```

```
      DY=B(2,J)-B(2,J-1)
      S(J)=S(J-1)+SQRTF(DX*DX+DY*DY)
706   FS(J)=B(2,J)*W*B(4,J)*(1.0-W*W)**G1
      IF(IP)708,707,708
707   SUM=0.0
      GO TO 709
708   SUM=FINAL(6,NN)
709   DO 710 J=IGO,LASTP
      K = J
      CALL PARAB(S(K),FS(K),D(1))
      ADD=POLNT(D(1),S(K),S(K+1))
      SUM = ADD + SUM
      DEL = XMASS - SUM
      IF(DEL)712,711,710
710   CONTINUE
      IF(IP)641,541,641
711   F1=1.0
      F2 = 0.0
      GO TO 717
712   AREA=ADD+DEL
      K=0
      XLO=S(J)
      XHI=S(J+1)
713   K=K+1
      XX=(XLO+XHI)*0.5
      YY=POLNT(D(1),S(J),XX)
      TEST=AREA-YY
      IF(TEST)714,716,715
714   XHI=XX
      IF(K-20)713,716,716
715   XLO=XX
      IF(K-20)713,716,716
716   DX=S(J+1)-S(J)
      F1=(XX-S(J))/DX
      F2=(S(J+1)-XX)/DX
717   DO 718 I=1,5
718   B(I,J+1)=B(I,J)*F2+B(I,J+1)*F1
      B(6,J+1) = 1.0/B(4,J+1)
      DO 719 K=1,6
719   WALL(K,ME)=B(K,J+1)
      LAST=J+1
      IF(IP)720,538,720
720   IF(N-ME)640,600,538
C
800   GO TO 17
804   END FILE 24
807   STOP 05314
      END
      FUNCTION POLNT(D,Y,X)
      DIMENSION D(3)
      D2 = D(2)*0.5
      D3 = D(3)*0.33333333
      POLNT = (X-Y)*(D(1)+(X+Y)*(D2+D3*X)+D3*Y*Y)
      RETURN
      END
```

APPENDIX II

SUBROUTINES USED

SQRTF — calculates square root of the argument

ASINF — calculates angle of argument (in radians)

COSRF — cosine, in radians

ATANF — gives arctan, in radians

SINRF — sine, in radians

FMA — calculates Mach number as a function of area ratio, (A/A* or A*/A), and gamma,
e.g., XM = FMA (RR, G)
where RR = area ratio
G = gamma

FMV — calculates Mach number as a function of Prandtl-Meyer angle and gamma,
e.g., XM = FMV (R, G)
where R = Prandtl-Meyer angle
G = gamma

PARAB — calculates the coefficients, A1, A2, and A3, of a parabolic fit through three points,
YY(1-3) = FUNCTION of XX(1-3)
i.e., $Y = A1 + A2X + A3X^2$

POLNT — integrates the area under the parabola $A1 + A2X + A3X^2$.
i.e., $\int_{x_2}^{x_1} (A1 + A2X + A3X^2)\, dX$
e.g., sum = POLNT (A(L), X_1, X_2)

OFELD — calculates X, Y, V/V_{max}, Mach angle, flow angle, and entropy at the intersection of a left and a right-running characteristic,
e.g., CALL OFELD(A(1, i), B(1, i), B(1, i+1), G)
where A(1, i) = X-coordinate of right-running characteristic
B(1, i) = X-coordinate of left-running characteristic
B(L, i+1) = X-coordinate of intersection
$G = \dfrac{2}{\gamma - 1}$

```
FUNCTION POLNT(D,Y,X)
DIMENSION D(3)
D2 = D(2)*0.5
D3 = D(3)*0.33333333
POLNT = (X-Y)*(D(1)+(X+Y)*(D2+D3*X)+D3*Y*Y)
RETURN
END
```

```
      FUNCTION FMV
      FUNCTION FMV RETURNS THE MACH NO. AS A FUNCTION OF GAMMA P.M. ANG
      FUNCTION FMV(R,G)
      A=SQRTF((G+1.0)/(G-1.0))
      B=1.0/A
      P1=4.898979
      R1=A* ATANF(B*P1)- ATANF(P1)
      IF(R-R1)1,10,2
 1    P2=2.828427
      GO TO 3
 2    P2=8.944272
 3    R2=A* ATANF(B*P2)- ATANF(P2)
      IF(R2-R)4,11,4
 4    P3=P1+(R-R1)*(P1-P2)/(R1-R2)
      IF(P3-1.0)14,15,15
14    P3=1.0
15    IF(ABSF(P2-P3)-0.0005)12,12,5
 5    R3=A* ATANF(B*P3)- ATANF(P3)
      P1=P2+(R-R2)*(P2-P3)/(R2-R3)
      IF(P1-1.0)16,17,17
16    P1=1.0
17    IF(ABSF(P3-P1)-0.0005)10,10,6
 6    R1=A* ATANF(B*P1)- ATANF(P1)
      P2=P3+(R-R3)*(P3-P1)/(R3-R1)
      IF(P2-1.0)18,19,19
18    P2=1.0
19    IF(ABSF(P1-P2)-0.0005)11,11,3
10    FMV=SQRTF(P1**2+1.0)
      RETURN
11    FMV=SQRTF(P2**2+1.0)
      RETURN
12    FMV=SQRTF(P3**2+1.0)
      RETURN
      END
```

```
C         SUBROUTINE PARAB
          SUBROUTINE PARAB(XX,YY,A)
C
C         SUBROUTINE PARAB RETURNS THE COEFFICIENTS A  OF A PARABOLIC FIT
C         THROUGH THREE POINTS YY(1-3) = FUNCTION OF XX(1-3)
C
          DIMENSION  XX(3),YY(3),A(3)
          X1 = XX(1)
          X2 = XX(2)
          X3 = XX(3)
          F1 = X1 - X2
          F2 = X2 - X3
          F3 = X3 - X1
          D  = -1.0/(F1*F2*F3)
          Y1 = YY(1)*F2
          Y2 = YY(2)*F3
          Y3 = YY(3)*F1
          A(1) = D*(Y1*X2*X3 + Y2*X1*X3 + Y3*X1*X2)
          A(2) = -D*(Y1*(X2+X3) + Y2*(X1+X3) + Y3*(X1+X2))
          A(3) = D*(Y1+Y2+Y3)
          RETURN
          END
```

```
      FUNCTION FMA(RR,G)

      FUNCTION FMA RETURNS THE MACH NO. AS A FUNCTION OF AREA RATIO
      RR=,AREA RATIO ( A/A* OR A*/A ) AND G=GAMMA

      IF(RR - 1.0)20,21,22
 20   R = RR
      GO TO 23
 21   FMA = 1.0
      RETURN
 22   R = 1.0/RR
 23   CONTINUE
      IF(G-GAMMA)1,2,1
  1   GAMMA=G
      C1=(G+1.0)/(2.0*(G-1.0))
      C2=((G+1.0)*0.5)**C1
      C3=0.5*(G-1.0)
  2   P1=5.0
      R1=C2*P1/(1.0+C3*P1*P1)**C1
      IF(R1-R)3,10,4
  3   P2=3.0
      GO TO 5
  4   P2=9.0
  5   R2=C2*P2/(1.0+C3*P2*P2)**C1
      IF(R2-R)6,11,6
  6   P3=P1+(R-R1)*(P1-P2)/(R1-R2)
      IF(P3-1.0)14,15,15
 14   P3=1.0
 15   IF(ABSF(P2-P3)-0.0005)12,12,7
  7   R3=C2*P3/(1.0+C3*P3*P3)**C1
      P1=P2+(R-R2)*(P2-P3)/(R2-R3)
      IF(P1-1.0)16,17,17
 16   P1=1.0
 17   IF(ABSF(P3-P1)-0.0005)10,10,8
  8   R1=C2*P1/(1.0+C3*P1*P1)**C1
      P2=P3+(R-R3)*(P3-P1)/(R3-R1)
      IF(P2-1.0)18,19,19
 18   P2=1.0
 19   IF(ABSF(P1-P2)-0.0005)11,11,5
 10   FMA=P1
      RETURN
 11   FMA=P2
      RETURN
 12   FMA=P3
      RETURN
      END
```

```
      SUBROUTINE OFELD (A,B,C,G)
      DIMENSION A(5),B(5),C(5)
      X1 = A(1)
      Y1 = A(2)
      W1 = A(3)
      SA1 = A(4)
      T1 = A(5)
      W13 = W1
C
      X2 = B(1)
      Y2 = B(2)
      W2 = B(3)
      SA2 = B(4)
      T2 = B(5)
      W23 = W2
C
      IF(SENSE SWITCH 4)91,92
   91 CONTINUE
      WRITE TAPE 12,DASH
      WRITE TAPE 12,(A(J),J=1,5)
      WRITE TAPE 12,(B(J),J=1,5)
      WRITE TAPE 12,BLANK
   92 CONTINUE
      DT = T1 - T2
      DW = W1 - W2
      C3 = 0.0
      I  = -1
C
   20 ST1  = SINRF(T1)
       HST1= ST1
      CT1  = COSRF(T1)
       HSA1= SA1
      CA1 = SQRTF(1.0 - SA1*SA1)
       HCA1= CA1
      ST2  = SINRF(T2)
       HST2= ST2
      CT2  = COSRF(T2)
       HSA2= SA2
      CA2 = SQRTF(1.0 - SA2*SA2)
       HCA2= CA2
      SINA = ST1*CA1 - CT1*SA1
        SA = SINA
      COSA = CT1*CA1 + ST1*SA1
        CA = COSA
      SINB = ST2*CA2 + CT2*SA2
        SB = SINB
      COSB = CT2*CA2 - ST2*SA2
        CB = COSB
      GO TO 40
C
   30 ST3  = SINRF(T3)
      CT3  = COSRF(T3)
      CA3 = SQRTF(1.0 - SA3*SA3)
       H1  = ST3*CA3
       H2  = CT3*SA3
```

```
      H3   = CT3*CA3
      H4   = ST3*SA3
      SINA = (SA + H1-H2)*0.5
      COSA = (CA + H3+H4)*0.5
      SINB = (SB + H1+H2)*0.5
      COSB = (CB + H3-H4)*0.5
      ST1  = (HST1 + ST3)*0.5
      SA1  = (HSA1 + SA3)*0.5
      CA1  = (HCA1 + CA3)*0.5
      ST2  = (HST2 + ST3)*0.5
      SA2  = (HSA2 + SA3)*0.5
      CA2  = (HCA2 + CA3)*0.5
      W13  = (W1 + W3)*0.5
      W23  = (W2 + W3)*0.5
      C3   = W3
C
   40 CONTINUE
      E  = SINA*COSB
      F  = COSA*SINB
      D  = F - E
      X3 = (F*X2 - E*X1 + COSA*COSB*(Y1-Y2))/D
      Y3 = (F*Y1 - E*Y2 + SINA*SINB*(X2-X1))/D
C
      DX = X3 - X1
      DY = Y3 - Y1
      IF(ABSF(DX) - ABSF(DY))41,42,42
   41 P1 = DY/SINA
      GO TO 43
   42 P1 = DX/COSA
   43 DX = X3 - X2
      DY = Y3 - Y2
      IF(ABSF(DX) - ABSF(DY))44,45,45
   44 P2 = DY/SINB
      GO TO 45
   45 P2 = DX/COSB
      P1 = ST1*SA1*P1*2.0/(Y1+Y3)
      P2 = ST2*SA2*P2*2.0/(Y2+Y3)
   50 Q1  = CA1/(SA1*W13)
      Q2  = CA2/(SA2*W23)
      Q   = Q2 + Q1
C
      T3  = (Q2*(P1 + T1 + Q1*DW) + Q1*(T2-P2))/Q
      W3  = (P1+P2 + Q1*W1 + Q2*W2 + DT)/Q
      WW  = W3*W3
      SA3 = SQRTF((1.0 - WW)/(G*WW))
C
      I = I + 1
      IF(SENSE SWITCH 4)93,94
   93 CONTINUE
      WRITE TAPE 12,P1,P2,Q1,Q2
      WRITE TAPE 12,X3,Y3,W3,SA3,T3
   94 CONTINUE
      IF(I)52,51,52
   51 TOLD = T3
      T3   = (T3 + (T1+T2)*0.5)*0.5
```

```
      GO TO 30
C
   52 IF(ABSF(T3-TOLD) - 0.00001)60,60,61
     *
   60 IF(ABSF(C3-W3) - 0.00001)70,70,61
     *
   61 IF(I-40)62,63,62
   62 TEMP = T3
      T3   = (T3 + TOLD)*0.5
      TOLD = TEMP
      GO TO 30
C
   63 SENSE LIGHT 1
   70 C(1) = X3
      C(2) = Y3
      C(3) = W3
      C(4) = SA3
      C(5) = T3
   80 RETURN
      DASH = DASH
      BLANK = BLANK
      END
```

APPENDIX III

FIELD POINT CALCULATION

The partial differential equations for supersonic, axially symmetric, irrotational flow are reduced to the following ordinary differential equations by the method of characteristics (Ref. 1):

1. $\frac{dY}{dX} = \tan(\theta - \alpha)$ (right-running)

2. $\frac{dY}{dX} = \tan(\theta + \alpha)$ (left-running)

3. $d\theta + \frac{\cot \alpha}{W}(dW) - \frac{\sin\theta \sin\alpha}{\sin(\theta+\alpha)} \frac{dY}{Y} = 0$ (right-running)

4. $d\theta - \frac{\cot \alpha}{W}(dW) + \frac{\sin\theta \sin\alpha}{\sin(\theta+\alpha)} \frac{dY}{Y} = 0$ (left-running)

Equations (1-4) are solved by finite difference methods in the following form:

1. $\frac{Y_c - Y_a}{X_c - X_a} \quad \frac{\sin(\theta - \alpha)}{\cos(\theta - \alpha)}$

2. $\frac{Y_c - Y_b}{X_c - X_a} \quad \frac{\sin(\theta + \alpha)}{\cos(\theta + \alpha)}$

1. $X_c \cdot \sin(\theta - \alpha) - Y_c \cdot \cos(\theta - \alpha) = X_a \cdot \sin(\theta - \alpha) - Y_a \cdot \cos(\theta - \alpha)$

2. $X_c \cdot \sin(\theta + \alpha) - Y_c \cdot \cos(\theta + \alpha) = X_b \cdot \sin(\theta + \alpha) - Y_b \cdot \cos(\theta + \alpha)$

Solving the system Eqs. (1) and (2), we have

$$X_c = \frac{\begin{vmatrix} X_a \cdot \sin(\theta - \alpha) - Y_a \cdot \cos(\theta - \alpha) & -\cos(\theta - \alpha) \\ X_b \cdot \sin(\theta + \alpha) - Y_b \cdot \cos(\theta + \alpha) & -\cos(\theta + \alpha) \end{vmatrix}}{\begin{vmatrix} \sin(\theta - \alpha) & -\cos(\theta - \alpha) \\ \sin(\theta + \alpha) & -\cos(\theta + \alpha) \end{vmatrix}}$$

$$Y_c = \frac{\begin{vmatrix} \sin(\theta - \alpha) & X_a \cdot \sin(\theta - \alpha) - Y_a \cdot \cos(\theta - \alpha) \\ \sin(\theta + \alpha) & X_b \cdot \sin(\theta + \alpha) - Y_b \cdot \cos(\theta + \alpha) \end{vmatrix}}{\begin{vmatrix} \sin(\theta - \alpha) & -\cos(\theta - \alpha) \\ \sin(\theta + \alpha) & -\cos(\theta + \alpha) \end{vmatrix}}$$

3. $\theta_c - \theta_a + \frac{\cot\alpha}{W}(W_c - W_a) - \frac{\sin\theta \sin\alpha}{\sin(\theta - \alpha)} \cdot \frac{dY}{Y} = 0$

4. $\theta_c - \theta_b - \frac{\cot\alpha}{W}(W_c - W_b) + \frac{\sin\theta \sin\alpha}{\sin(\theta + \alpha)} \cdot \frac{dY}{Y} = 0$

APPENDIX IV

DATA PRESENTATION

This appendix given a sample of the output obtained by the methods previously outlined. For each of the two principle sections, there is given a page of wall points, a page of axis points, and several pages of characteristic lines including the first and last characteristics in the respective regions.

As indicated in Section 2.3, each characteristic originating on line EF has an initial mass integration value which is computed at the first point of that characteristic. This initial value of mass appears in the output as the first value in column seven.

SAMPLE CALCULATIONS THROAT REGION

INPUT

NUMBER OF POINTS ON FIRST CHARACTERISTIC (M)= 15

NUMBER OF POINTS ON AXIS (N)= 20

GAMMA= 1.4000

INFLECTION ANGLE (ETA)= 12.000 DEGREES

COORDINATE OF INFLECTION POINT (XC)= .00000

FACTORS IN V/VMAX TO DETERMINE X (X1)= .47270

(X2)= 1.91607

POWER GOVERNING AXIS DISTRIBUTION (P)= 2.00000

COEFFICIENTS IN TERMS OF V/VMAX

C(1)= 4.0824825-01

C(2)= 5.5127312-01

C(3)= 1.0438091-02

C(4)=-3.6969777-01

C(5)= 2.2921343-01

C(6)=-4.2703583-02

AXIS

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	1.9160700+00	.0000000+00	7.8677154-01	2.0539411+01	.0000000+00	2.8502078+00
2	1.7681353+00	.0000000+00	7.6801048-01	2.1896281+01	.0000000+00	2.6814859+00
3	1.6281957+00	.0000000+00	7.4668756-01	2.3477770+01	.0000000+00	2.5100827+00
4	1.4962527+00	.0000000+00	7.2289589-01	2.5306148+01	.0000000+00	2.3394283+00
5	1.3723068+00	.0000000+00	6.9695680-01	2.7396609+01	.0000000+00	2.1732175+00
6	1.2563578+00	.0000000+00	6.6936527-01	2.9759848+01	.0000000+00	2.0146436+00
7	1.1484053+00	.0000000+00	6.4072997-01	3.2403734+01	.0000000+00	1.8660831+00
8	1.0484490+00	.0000000+00	6.1171489-01	3.5334078+01	.0000000+00	1.7290779+00
9	9.5648887-01	.0000000+00	5.8298770-01	3.8554544+01	.0000000+00	1.6044684+00
10	8.7252528-01	.0000000+00	5.5517809-01	4.2065997+01	.0000000+00	1.4925681+00
11	7.9655846-01	.0000000+00	5.2884703-01	4.5865592+01	.0000000+00	1.3933238+00
12	7.2858834-01	.0000000+00	5.0446791-01	4.9945788+01	.0000000+00	1.3064451+00
13	6.6861469-01	.0000000+00	4.8241846-01	5.4293611+01	.0000000+00	1.2314991+00
14	6.1663717-01	.0000000+00	4.6298226-01	5.8890218+01	.0000000+00	1.1679802+00
15	5.7265632-01	.0000000+00	4.4635751-01	6.3710936+01	.0000000+00	1.1153606+00
16	5.3667210-01	.0000000+00	4.3267061-01	6.8725887+01	.0000000+00	1.0731280+00
17	5.0868427-01	.0000000+00	4.2199273-01	7.3900841+01	.0000000+00	1.0408175+00
18	4.8869300-01	.0000000+00	4.1435731-01	7.9198237+01	.0000000+00	1.0180381+00
19	4.7669825-01	.0000000+00	4.0977539-01	8.4578386+01	.0000000+00	1.0044937+00
20	4.7270000-01	.0000000+00	4.0824825-01	.0000000+00	.0000000+00	9.9999985-01

FIRST

PCINT	X	Y	V/VMAX	MACH ANG.(D)	FLCW ANG.(D)	MACH NO.
1	1.9161003+00	.0000000+00	7.8677156-01	2.0539408+01	.0000000+00	2.8502083+00
2	1.9952818+00	2.9851568-02	7.9549330-01	1.9917231+01	8.5714280-01	2.9354581+00
3	2.0801352+00	6.2256075-02	8.0402024-01	1.9313122+01	1.7142856+00	3.0236094+00
4	2.1711983+00	9.7508622-02	8.1235499-01	1.8725836+01	2.5714284+00	3.1148757+00
5	2.2690672+00	1.3594295-01	8.2049928-01	1.8154280+01	3.4285712+00	3.2094815+00
6	2.3744160+00	1.7793786-01	8.2845491-01	1.7597439+01	4.2857140+00	3.3076735+00
7	2.4880016+00	2.2392418-01	8.3622333-01	1.7054386+01	5.1428568+00	3.4097186+00
8	2.6106818+00	2.7439365-01	8.4380591-01	1.6524266+01	5.9999991+00	3.5159095+00
9	2.7434285+00	3.2990935-01	8.5120382-01	1.6006292+01	6.8571423+00	3.6265660+00
10	2.8873420+00	3.9111700-01	8.5841789-01	1.5499752+01	7.7142849+00	3.7420356+00
11	3.0436861+00	4.5876182-01	8.6544925-01	1.5003956+01	8.5714280+00	3.8627077+00
12	3.2139020+00	5.3370469-01	8.7229867-01	1.4518279+01	9.4285706+00	3.9890085+00
13	3.3996408+00	6.1694376-01	8.7896664-01	1.4042151+01	1.0285713+01	4.1214054+00
14	3.6028115+00	7.0964250-01	8.8545385-01	1.3575026+01	1.1142856+01	4.2604234+00
15	3.8256230+00	8.1316119-01	8.9176084-01	1.3116394+01	1.1999998+01	4.4066454+00

CHAR 7

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	1.1484053+00	.0000000+00	6.4072997-01	3.2403734+01	.0000000+00	1.8660831+00
2	1.1998655+00	3.2461364-02	6.5515689-01	3.1044488+01	1.0392350+00	1.9390988+00
3	1.2499484+00	6.3743327-02	6.6858048-01	2.9793983+01	2.1012785+00	2.0125469+00
4	1.2982467+00	9.3751433-02	6.8206792-01	2.8651865+01	3.1588559+00	2.0855648+00
5	1.3445549+00	1.2247372-01	6.9427062-01	2.7619846+01	4.1863989+00	2.1570181+00
6	1.3889131+00	1.5001028-01	7.0549145-01	2.6696165+01	5.1605961+00	2.2258865+00
7	1.4314908+00	1.7651203-01	7.1573754-01	2.5871958+01	6.0707354+00	2.2916781+00
8	1.4747146+00	2.0352053-01	7.2555748-01	2.5097745+01	6.9585444+00	2.3575798+00
9	1.5206479+00	2.3236074-01	7.3527285-01	2.4345594+01	7.8456521+00	2.4257743+00
10	1.5694731+00	2.6319018-01	7.4486052-01	2.3615594+01	8.7320510+00	2.4962654+00
11	1.6214223+00	2.9620383-01	7.5429984-01	2.2907672+01	9.6165981+00	2.5690609+00
12	1.6767485+00	3.3161656-01	7.6357897-01	2.2221154+01	1.0499024+01	2.6442253+00
13	1.7357302+00	3.6966738-01	7.7269056-01	2.1555119+01	1.1379360+01	2.7218577+00
14	1.7986778+00	4.1062422-01	7.8162980-01	2.0908562+01	1.2257715+01	2.8020810+00
15	1.8449057+00	4.4092960-01	7.8766911-01	2.0475158+01	1.2853944+01	2.8587663+00

CHAR 14

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	6.1663717-01	.0000000+00	4.6298226-01	5.8890218+01	.0000000+00	1.1679802+00
2	6.4129981-01	3.9233619-02	4.7301281-01	5.6408236+01	3.8496754-01	1.2004790+00
3	6.6711163-01	7.7243581-02	4.8398893-01	5.3957683+01	8.8622016-01	1.2367319+00
4	6.9371605-01	1.1378302-01	4.9594930-01	5.1537991+01	1.5002737+00	1.2771053+00
5	7.2071533-01	1.4862064-01	5.0872992-01	4.9184811+01	2.2261131+00	1.3213150+00
6	7.4767870-01	1.8156254-01	5.2209978-01	4.6932763+01	3.0553935+00	1.3688263+00
7	7.7415013-01	2.1243068-01	5.3583572-01	4.4803650+01	3.9782077+00	1.4190850+00
8	7.9974149-01	2.4114160-01	5.4964070-01	4.2821907+01	4.9724523+00	1.4711901+00
9	8.1794774-01	2.6100686-01	5.5985933-01	4.1442861+01	5.7536622+00	1.5108642+00

CHAR 20

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	4.7270000-01	.0000000+00	4.0824825-01	.0000000+00	.0000000+00	9.9999985-01
2	4.7394504-01	3.1714399-02	4.0929893-01	8.5501140+01	3.1320498-03	1.0030906+00
3	4.7776127-01	6.6313669-02	4.1168700-01	8.1877508+01	2.8380085-02	1.0101333+00
4	4.8387963-01	1.0166363-01	4.1535182-01	7.8361874+01	9.1275489-02	1.0209902+00
5	4.9210774-01	1.3655434-01	4.2048343-01	7.4791447+01	2.1415192-01	1.0362937+00
6	5.0232067-01	1.7070059-01	4.2699439-01	7.1275463+01	4.1289559-01	1.0558849+00
7	5.1430715-01	2.0385075-01	4.3481791-01	6.7848511+01	7.0198594-01	1.0796918+00
8	5.2392601-01	2.2703553-01	4.4135463-01	6.5401202+01	9.8139678-01	1.0998137+00

WALL

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	5.1659679-01	2.0936958-01	4.3637388-01	6.7243410+01	7.6849615-01	1.0844146+00
2	5.3236531-01	2.0958211-01	4.4267507-01	6.4953063+01	9.8139615-01	1.1037999+00
3	5.6188641-01	2.1016633-01	4.5446819-01	6.124255[illegible]+01	1.3749283+00	1.1406875+00
4	6.0159163-01	2.1130005-01	4.7022952-01	5.7084779+01	1.9003177+00	1.1912199+00
5	6.5119480-01	2.1325026-01	4.8975707-01	5.2771310+01	2.5526800+00	1.2559231+00
6	7.1099133-01	2.1638824-01	5.1294391-01	4.8454817+01	3.3308082+00	1.3361250+00
7	7.8184284-01	2.2106113-01	5.3998546-01	4.4200965+01	4.2770760+00	1.4343556+00
8	8.6463544-01	2.2805722-01	5.7041743-01	4.0093121+01	5.3586052+00	1.5527183+00
9	9.6099059-01	2.3816480-01	6.0400141-01	3.6169147+01	6.5919465+00	1.6944240+00
10	1.0730759+00	2.5248676-01	6.3984620-01	3.2491226+01	7.9194868+00	1.8616065+00
11	1.2036826+00	2.7222666-01	6.7621061-01	2.9159999+01	9.1905049+00	2.0523341+00
12	1.3559671+00	2.9841055-01	7.1113326-01	2.6241486+01	1.0221735+01	2.2616482+00
13	1.5336236+00	3.3176324-01	7.4364038-01	2.3708614+01	1.0958861+01	2.4870336+00
14	1.7406534+00	3.7287075-01	7.7338972-01	2.1504446+01	1.1448058+01	2.7279663+00
15	1.9813879+00	4.2237944-01	8.0005758-01	1.9593565+01	1.1735549+01	2.9819967+00
16	2.2602859+00	4.8080762-01	8.2381568-01	1.7921965+01	1.1894637+01	3.2496925+00
17	2.5812845+00	5.4876196-01	8.4459651-01	1.6468681+01	1.1963565+01	3.5274462+00
18	2.9477854+00	6.2658663-01	8.6272046-01	1.5196376+01	1.1992298+01	3.8149276+00
19	3.3614256+00	7.1447992-01	8.7832743-01	1.4087849+01	1.2003126+01	4.1083057+00
20	3.8256230+00	8.1316119-01	8.9176084-01	1.3116394+01	1.1999998+01	4.4066454+00

SAMPLE CALCULATIONS   DOWNSTREAM REGION

INPUT

NUMBER OF POINTS ON FIRST CHARACTERISTIC (M)= 40

NUMBER OF POINTS ON AXIS (N)= 6

GAMMA= 1.4000

INFLECTION ANGLE (ETA)= 12.000 DEGREES

COORDINATE OF INFLECTION POINT (XC)= .00000

FACTORS IN V/VMAX TO DETERMINE X (X1)= 13.01549

(X2)= 15.21197

POWER GOVERNING AXIS DISTRIBUTION (P)= 1.00000

COEFFICIENTS IN TERMS OF V/VMAX

C(1)= 9.6127941-01

C(2)= 5.4219450-03

C(3)=-5.4219450-03

C(4)= 1.8073150-03

C(5)= .0000000+00

C(6)= .0000000+00

AXIS

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	1.3015491+01	.0000000+00	9.6127941-01	7.3658990+00	.0000000+00	7.7999875+00
2	1.3454787+01	.0000000+00	9.6216137-01	7.2760014+00	.0000000+00	7.8958308+00
3	1.3894083+01	.0000000+00	9.6269634-01	7.2210610+00	.0000000+00	7.9555832+00
4	1.4333379+01	.0000000+00	9.6297105-01	7.1927242+00	.0000000+00	7.9867587+00
5	1.4772675+01	.0000000+00	9.6307226-01	7.1822632+00	.0000000+00	7.9983301+00
6	1.5211972+01	.0000000+00	9.6308672-01	7.1807683+00	.0000000+00	7.9999878+00

FIRST

PCINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	1.3016149+01	.0000000+00	9.6128115-01	7.3657208+00	.0000000+00	7.8001747+00
2	1.2491085+01	6.7080898-02	9.5993501-01	7.5013697+00	3.0769266-01	7.6599080+00
3	1.1995820+01	1.2884605-01	9.5856593-01	7.6374856+00	6.1538532-01	7.5241795+00
4	1.1528195+01	1.8574383-01	9.5717389-01	7.7740839+00	9.2307741-01	7.3927642+00
5	1.1086247+01	2.3818010-01	9.5575890-01	7.9111698+00	1.2307695+00	7.2654545+00
6	1.0668183+01	2.8652272-01	9.5432095-01	8.0487593+00	1.5384621+00	7.1420527+00
7	1.0272348+01	3.3110474-01	9.5286004-01	8.1868633+00	1.8461542+00	7.0223743+00
8	9.8972516+00	3.7222996-01	9.5137619-01	8.3254887+00	2.1538463+00	6.9062501+00
9	9.5415071+00	4.1017423-01	9.4986940-01	8.4644487+00	2.4615390+00	6.7935175+00
10	9.2038263+00	4.4518788-01	9.4833963-01	8.6043570+00	2.7692310+00	6.6840221+00
11	8.8830563+00	4.7750092-01	9.4678696-01	8.7446211+00	3.0769231+00	6.5776244+00
12	8.5780946+00	5.0732138-01	9.4521130-01	8.8854576+00	3.3846158+00	6.4741841+00
13	8.2879571+00	5.3484083-01	9.4361270-01	9.0268773+00	3.6923079+00	6.3735776+00
14	8.0117234+00	5.6023427-01	9.4199114-01	9.1688912+00	4.0000000+00	6.2756842+00
15	7.7485398+00	5.8366186-01	9.4034663-01	9.3115130+00	4.3076926+00	6.1803894+00
16	7.4976256+00	6.0527093-01	9.3867917-01	9.4547536+00	4.6153847+00	6.0875878+00
17	7.2582455+00	6.2519611-01	9.3698877-01	9.5986273+00	4.9230768+00	5.9971773+00
18	7.0297157+00	6.4356086-01	9.3527537-01	9.7431508+00	5.2307695+00	5.9090594+00
19	6.8114152+00	6.6047976-01	9.3353902-01	9.8883320+00	5.5384616+00	5.8231462+00
20	6.6027554+00	6.7605747-01	9.3177971-01	1.0034187+01	5.8461537+00	5.7393500+00
21	6.4031911+00	6.9039071-01	9.2999744-01	1.0180730+01	6.1538463+00	5.6575898+00
22	6.2122102+00	7.0356793-01	9.2819215-01	1.0327978+01	6.4615378+00	5.5777854+00
23	6.0293494+00	7.1567264-01	9.2636392-01	1.0475938+01	6.7692305+00	5.4998669+00
24	5.8541614+00	7.2677993-01	9.2451272-01	1.0624629+01	7.0769226+00	5.4237622+00
25	5.6862304+00	7.3695978-01	9.2263849-01	1.0774071+01	7.3846147+00	5.3494029+00
26	5.5251775+00	7.4627794-01	9.2074130-01	1.0924270+01	7.6923073+00	5.2767284+00
27	5.3706380+00	7.5479389-01	9.1882109-01	1.1075247+01	7.9999994+00	5.2056761+00
28	5.2222748+00	7.6256346-01	9.1687789-01	1.1227016+01	8.3076915+00	5.1361893+00
29	5.0797715+00	7.6963839-01	9.1491166-01	1.1379596+01	8.6153842+00	5.0682123+00
30	4.9428293+00	7.7606611-01	9.1292237-01	1.1533003+01	8.9230763+00	5.0016915+00
31	4.8111733+00	7.8189167-01	9.1091007-01	1.1687252+01	9.2307684+00	4.9365792+00
32	4.6845403+00	7.8715622-01	9.0887473-01	1.1842361+01	9.5384610+00	4.8728262+00
33	4.5626840+00	7.9189791-01	9.0681633-01	1.1998347+01	9.8461531+00	4.8103870+00
34	4.4453752+00	7.9615286-01	9.0473488-01	1.2155227+01	1.0153845+01	4.7492185+00
35	4.3323941+00	7.9995394-01	9.0263036-01	1.2313022+01	1.0461537+01	4.6892778+00
36	4.2235363+00	8.0333214-01	9.0050274-01	1.2471750+01	1.0769230+01	4.6305252+00
37	4.1186065+00	8.0631585-01	8.9835198-01	1.2631431+01	1.1076922+01	4.5729212+00
38	4.0174211+00	8.0893160-01	8.9617802-01	1.2792091+01	1.1384614+01	4.5164281+00
39	3.9198167+00	8.1120613-01	8.9398104-01	1.2953735+01	1.1692306+01	4.4610156+00
40	3.8256243+00	8.1316152-01	8.9176088-01	1.3116391+01	1.1999999+01	4.4066463+00

CHAR 6

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	1.5211972+01	.0000000+00	9.6308672-01	7.1807683+00	.0000000+00	7.9999878+00
2	1.4992288+01	2.7676075-02	9.6307944-01	7.1815212+00	1.9201940-03	7.9991533+00
3	1.4772061+01	5.5401137-02	9.6304273-01	7.1853176+00	1.3888795-02	7.9949497+00
4	1.4550000+01	8.3298036-02	9.6295186-01	7.1947067+00	4.4776165-02	7.9845706+00
5	1.4323960+01	1.1156713-01	9.6277770-01	7.2126775+00	1.0471410-01	7.9647816+00
6	1.4091433+01	1.4041875-01	9.6249137-01	7.2421482+00	2.0295899-01	7.9325416+00
7	1.3521563+01	2.0967691-01	9.6146759-01	7.3467874+00	5.2730097-01	7.8201662+00
8	1.2981790+01	2.7318902-01	9.6029288-01	7.4654888+00	8.6439857-01	7.6965135+00
9	1.2471038+01	3.3135501-01	9.5904732-01	7.5898321+00	1.1975195+00	7.5711426+00
10	1.1987605+01	3.8464635-01	9.5775403-01	7.7173714+00	1.5262623+00	7.4467588+00
11	1.1529877+01	4.3350054-01	9.5642314-01	7.8470335+00	1.8517382+00	7.3244619+00
12	1.1096250+01	4.7830061-01	9.5505993-01	7.9782637+00	2.1746451+00	7.2047464+00
13	1.0685220+01	5.1938889-01	9.5366691-01	8.1107934+00	2.4957105+00	7.0877895+00
14	1.0295317+01	5.5707946-01	9.5224643-01	8.2443854+00	2.8151419+00	6.9737137+00
15	9.9251976+00	5.9165392-01	9.5079955-01	8.3789325+00	3.1332860+00	6.8625117+00
16	9.5736241+00	6.2336595-01	9.4932693-01	8.5143683+00	3.4504636+00	6.7541372+00
17	9.2394289+00	6.5244726-01	9.4782922-01	8.6506343+00	3.7667773+00	6.6485356+00
18	8.9215437+00	6.7910758-01	9.4630711-01	8.7876692+00	4.0823138+00	6.5456536+00
19	8.6189686+00	7.0353852-01	9.4476074-01	8.9254638+00	4.3972784+00	6.4453991+00
20	8.3307765+00	7.2591481-01	9.4319047-01	9.0639924+00	4.7116784+00	6.3476962+00
21	8.0561097+00	7.4639600-01	9.4159648-01	9.2032452+00	5.0256042+00	6.2524587+00
22	7.7941621+00	7.6512852-01	9.3997881-01	9.3432268+00	5.3391525+00	6.1595967+00
23	7.5441875+00	7.8224622-01	9.3833767-01	9.4839269+00	5.6523770+00	6.0690328+00
24	7.3054983+00	7.9787153-01	9.3667330-01	9.6253346+00	5.9652309+00	5.9806934+00
25	7.0774452+00	8.1211737-01	9.3498555-01	9.7674723+00	6.2778413+00	5.8944879+00
26	6.8594275+00	8.2508722-01	9.3327466-01	9.9103295+00	6.5901749+00	5.8103500+00
27	6.6508813+00	8.3687641-01	9.3154062-01	1.0053917+01	6.9022965+00	5.7282029+00
28	6.4512890+00	8.4757226-01	9.2978353-01	1.0198239+01	7.2141976+00	5.6479787+00
29	6.2601586+00	8.5725562-01	9.2800334-01	1.0343312+01	7.5259473+00	5.5696061+00
30	6.0770319+00	8.6600107-01	9.2620027-01	1.0489128+01	7.8374926+00	5.4930281+00
31	5.9014858+00	8.7387714-01	9.2437429-01	1.0635705+01	8.1488550+00	5.4181791+00
32	5.7331171+00	8.8094737-01	9.2252517-01	1.0783072+01	8.4600954+00	5.3449899+00
33	5.5715532+00	8.8727034-01	9.2065320-01	1.0931220+01	8.7712018+00	5.2734141+00
34	5.4164417+00	8.9290025-01	9.1875831-01	1.1080166+01	9.0821741+00	5.2033936+00
35	5.2674540+00	8.9788735-01	9.1684065-01	1.1229916+01	9.3930002+00	5.1348802+00
36	5.1242823+00	9.0227801-01	9.1490016-01	1.1380486+01	9.7037250+00	5.0678211+00
37	4.9866361+00	9.0611525-01	9.1293669-01	1.1531904+01	1.0014391+01	5.0021621+00
38	4.8542423+00	9.0943893-01	9.1095036-01	1.1684174+01	1.0324940+01	4.9378617+00
39	4.7268463+00	9.1228611-01	9.0894115-01	1.1837315+01	1.0635411+01	4.8748741+00
40	4.6042041+00	9.1469119-01	9.0690913-01	1.1991334+01	1.0945791+01	4.8131594+00
41	4.4860912+00	9.1668602-01	9.0485428-01	1.2146252+01	1.1256081+01	4.7526752+00
42	4.3722916+00	9.1830034-01	9.0277650-01	1.2302092+01	1.1566325+01	4.6933800+00
43	4.2626013+00	9.1956167-01	9.0067581-01	1.2458868+01	1.1876494+01	4.6352371+00
44	4.2613418+00	9.1957465-01	9.0065007-01	1.2460784+01	1.1880418+01	4.6345355+00

CHAR 7

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.	
2	1.5884793+01	8.4767692-02	9.6308672-01	7.1807683+00	.0000000+00	4.8910442-06	(MASS)
3	1.5665007+01	1.1245630-01	9.6308285-01	7.1811677+00	1.6364993-03	7.9995443+00	
4	1.5444182+01	1.4026169-01	9.6305919-01	7.1836148+00	1.1582197-02	7.9968338+00	
5	1.5220363+01	1.6838651-01	9.6299500-01	7.1902502+00	3.7338183-02	7.9894934+00	
6	1.4990987+01	1.9709044-01	9.6286096-01	7.2040906+00	9.0316627-02	7.9742247+00	
7	1.4752964+01	2.2665456-01	9.6262948-01	7.2279440+00	1.7981749-01	7.9480471+00	
8	1.4164562+01	2.9824036-01	9.6175245-01	7.3177855+00	4.9287429-01	7.8509894+00	
9	1.3605111+01	3.6404649-01	9.6070023-01	7.4244874+00	8.3309891-01	7.7387766+00	
10	1.3074709+01	4.2427235-01	9.5955826-01	7.5390096+00	1.1749941+00	7.6218844+00	
11	1.2571945+01	4.7937094-01	9.5835609-01	7.6581923+00	1.5144089+00	7.5039572+00	
12	1.2095151+01	5.2978279-01	9.5710745-01	7.7805606+00	1.8505884+00	7.3866487+00	
13	1.1642974+01	5.7590736-01	9.5582004-01	7.9052844+00	2.1840369+00	7.2708305+00	
14	1.1213883+01	6.1811478-01	9.5449829-01	8.0318834+00	2.5151235+00	7.1569609+00	
15	1.0806450+01	6.5673802-01	9.5314574-01	8.1599853+00	2.8439888+00	7.0453480+00	
16	1.0419349+01	6.9207683-01	9.5176407-01	8.2894073+00	3.1710164+00	6.9360999+00	
17	1.0051350+01	7.2440156-01	9.5035482-01	8.4199901+00	3.4965107+00	6.8292879+00	
18	9.7012890+00	7.5395855-01	9.4891890-01	8.5516363+00	3.8206829+00	6.7249197+00	
19	9.3680956+00	7.8097060-01	9.4745741-01	8.6842405+00	4.1436195+00	6.6230034+00	
20	9.0507631+00	8.0564169-01	9.4597066-01	8.8177695+00	4.4655642+00	6.5234852+00	
21	8.7483522+00	8.2815732-01	9.4445933-01	8.9521608+00	4.7865763+00	6.4263337+00	
22	8.4599926+00	8.4868680-01	9.4292375-01	9.0873880+00	5.1067830+00	6.3314906+00	
23	8.1848629+00	8.6738560-01	9.4136407-01	9.2234379+00	5.4263103+00	6.2388885+00	
24	7.9222008+00	8.8439561-01	9.3978063-01	9.3602861+00	5.7452134+00	6.1484703+00	
25	7.6713039+00	8.9984642-01	9.3817369-01	9.4979151+00	6.0635035+00	6.0601763+00	
26	7.4315040+00	9.1385777-01	9.3654336-01	9.6363222+00	6.3813008+00	5.9739383+00	
27	7.2021851+00	9.2653896-01	9.3488986-01	9.7754937+00	6.6986203+00	5.8896980+00	
28	6.9827652+00	9.3799089-01	9.3321314-01	9.9154438+00	7.0155250+00	5.8073830+00	
29	6.7727101+00	9.4830587-01	9.3151353-01	1.0056150+01	7.3320183+00	5.7269435+00	
30	6.5715111+00	9.5756926-01	9.2979090-01	1.0197636+01	7.6481893+00	5.6483092+00	
31	6.3786948+00	9.6585963-01	9.2804556-01	1.0339884+01	7.9639936+00	5.5714322+00	
32	6.1938218+00	9.7324931-01	9.2627746-01	1.0482909+01	8.2794785+00	5.4962507+00	
33	6.0164728+00	9.7980523-01	9.2448653-01	1.0626726+01	8.5947153+00	5.4227047+00	
34	5.8462620+00	9.8558906-01	9.2267291-01	1.0771336+01	8.9096765+00	5.3507447+00	
35	5.6828221+00	9.9065790-01	9.2083661-01	1.0916750+01	9.2243805+00	5.2803192+00	
36	5.5258118+00	9.9506450-01	9.1897786-01	1.1062960+01	9.5388082+00	5.2113857+00	
37	5.3749098+00	9.9885769-01	9.1709651-01	1.1209992+01	9.8530172+00	5.1438897+00	
38	5.2298125+00	1.0020826+00	9.1519266-01	1.1357850+01	1.0167053+01	5.0777881+00	
39	5.0902355+00	1.0047811+00	9.1326628-01	1.1506550+01	1.0480905+01	5.0130348+00	
40	4.9559124+00	1.0069920+00	9.1131732-01	1.1656109+01	1.0794587+01	4.9495855+00	
41	4.8265888+00	1.0087512+00	9.0934597-01	1.1806528+01	1.1108080+01	4.8874044+00	
42	4.7020292+00	1.0100922+00	9.0735211-01	1.1957829+01	1.1421405+01	4.8264483+00	
43	4.5820076+00	1.0110460+00	9.0533569-01	1.2110030+01	1.1734591+01	4.7666773+00	
44	4.5353376+00	1.0113247+00	9.0451646-01	1.2171643+01	1.1861999+01	4.7429096+00	

CHAR 15

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.	
10	2.1267366+01	7.6290921-01	9.6308672-01	7.1807683+00	.0000000+00	3.9617458-04	(MASS)
11	2.1047132+01	7.9065502-01	9.6308493-01	7.1809528+00	8.2235011-04	7.9997830+00	
12	2.0823545+01	8.1881638-01	9.6307451-01	7.1820300+00	5.6506034-03	7.9985890+00	
13	2.0591956+01	8.4796024-01	9.6304433-01	7.1851509+00	1.9491453-02	7.9951332+00	
14	2.0345768+01	8.7887540-01	9.6297859-01	7.1919450+00	4.9382033-02	7.9876198+00	
15	2.0078032+01	9.1235510-01	9.6285723-01	7.2044750+00	1.0387169-01	7.9738012+00	
16	1.9373200+01	9.9914109-01	9.6236352-01	7.2552775+00	3.1582309-01	7.9182632+00	
17	1.8681285+01	1.0821078+00	9.6170076-01	7.3230544+00	5.8602931-01	7.8453714+00	
18	1.8014259+01	1.1595981+00	9.6093284-01	7.4009984+00	8.8379433-01	7.7632000+00	
19	1.7375153+01	1.2313133+00	9.6008749-01	7.4860975+00	1.1971662+00	7.6754453+00	
20	1.6764182+01	1.2973871+00	9.5918141-01	7.5765189+00	1.5197548+00	7.5843687+00	
21	1.6180801+01	1.3580798+00	9.5822549-01	7.6710586+00	1.8478482+00	7.4914464+00	
22	1.5623855+01	1.4137280+00	9.5722654-01	7.7689496+00	2.1794430+00	7.3976195+00	
23	1.5092195+01	1.4646644+00	9.5619004-01	7.8695845+00	2.5129854+00	7.3036047+00	
24	1.4584538+01	1.5112251+00	9.5511990-01	7.9725232+00	2.8475852+00	7.2099009+00	
25	1.4099660+01	1.5537267+00	9.5401876-01	8.0774645+00	3.1827239+00	7.1168400+00	
26	1.3636342+01	1.5924700+00	9.5288869-01	8.1841716+00	3.5180372+00	7.0246685+00	
27	1.3193492+01	1.6277301+00	9.5173185-01	8.2924090+00	3.8531298+00	6.9336068+00	
28	1.2769995+01	1.6597687+00	9.5054925-01	8.4020571+00	4.1879231+00	6.8437594+00	
29	1.2364832+01	1.6888257+00	9.4934207-01	8.5129835+00	4.5[illegible]23010+00	6.7552277+00	
30	1.1977049+01	1.7151226+00	9.4811161-01	8.6250517+00	4.8560785+00	6.6601056+00	
31	1.1605689+01	1.7388676+00	9.4685775-01	8.7382596+00	5.1894579+00	6.5823754+00	
32	1.1249917+01	1.7602487+00	9.4558180-01	8.8524741+00	5.5221967+00	6.4981134+00	
33	1.0908934+01	1.7794409+00	9.4428420-01	8.9676495+00	5.8543235+00	6.4153253+00	
34	1.0581955+01	1.7966075+00	9.4296516-01	9.0837577+00	6.1858701+00	6.3339995+00	
35	1.0268272+01	1.8118975+00	9.4162518-01	9.2007500+00	6.5168414+00	6.2541398+00	
36	9.9672031+00	1.8254496+00	9.4026453-01	9.3185976+00	6.8472421+00	6.1757321+00	
37	9.6781246+00	1.8373913+00	9.3888364-01	9.4372624+00	7.1770166+00	6.0987684+00	
38	9.6191667+00	1.8396950+00	9.3858728-01	9.4626100+00	7.2477775+00	6.0825800+00	

CHAR 23

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.	
18	2.6649939+01	1.4410507+00	9.6308672-01	7.1807683+00	.0000000+00	1.4135117-03	(MASS)
19	2.6429393+01	1.4688359+00	9.6308516-01	7.1809293+00	6.9260668-04	7.9998092+00	
20	2.6204029+01	1.4972227+00	9.6307722-01	7.1817504+00	4.4034243-03	7.9988993+00	
21	2.5967243+01	1.5270283+00	9.6305423-01	7.1841282+00	1.5088305-02	7.9962660+00	
22	2.5709681+01	1.5593958+00	9.6300389-01	7.1893312+00	3.8319094-02	7.9905091+00	
23	2.5420982+01	1.5955569+00	9.6291017-01	7.1990125+00	8.1213124-02	7.9798206+00	
24	2.4629440+01	1.6934848+00	9.6252909-01	7.2382704+00	2.5014287-01	7.9367680+00	
25	2.3829899+01	1.7902671+00	9.6199969-01	7.2925438+00	4.7613372-01	7.8780167+00	
26	2.3045732+01	1.8826531+00	9.6137278-01	7.3564206+00	7.3351656-01	7.8099818+00	
27	2.2285487+01	1.9695286+00	9.6067087-01	7.4274484+00	1.0114538+00	7.7357091+00	
28	2.1552441+01	2.0505609+00	9.5990853-01	7.5040214+00	1.3033269+00	7.6572170+00	
29	2.0847808+01	2.1257404+00	9.5909577-01	7.5850244+00	1.6049362+00	7.5759136+00	
30	2.0171424+01	2.1952531+00	9.5823950-01	7.6696790+00	1.9135914+00	7.4927857+00	
31	1.9522790+01	2.2593409+00	9.5734495-01	7.7573925+00	2.2273181+00	7.4085730+00	
32	1.8900998+01	2.3182955+00	9.5641650-01	7.8476769+00	2.5446217+00	7.3238654+00	
33	1.8304995+01	2.3724206+00	9.5545686-01	7.9402130+00	2.8646722+00	7.2390496+00	
34	1.7733666+01	2.4220187+00	9.5446869-01	8.0347023+00	3.1866429+00	7.1544667+00	
35	1.7185971+01	2.4673768+00	9.5345407-01	8.1309077+00	3.5099629+00	7.0703731+00	
36	1.6833335+01	2.4954010+00	9.5275689-01	8.1965532+00	3.7288582+00	7.0141298+00	

CHAR 31

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.	
26	3.2032512+01	2.1191923+00	9.6308672-01	7.1807683+00	.0000000+00	3.0569027-03	(MASS)
27	3.1811674+01	2.1470143+00	9.6308516-01	7.1809293+00	7.0704218-04	7.9998092+00	
28	3.1584878+01	2.1755822+00	9.6307853-01	7.1816152+00	3.7809070-03	7.9990497+00	
29	3.1343863+01	2.2059242+00	9.6305902-01	7.1836320+00	1.2861266-02	7.9968147+00	
30	3.1077012+01	2.2394718+00	9.6301645-01	7.1880334+00	3.2600104-02	7.9919441+00	
31	3.0771034+01	2.2778305+00	9.6293706-01	7.1962348+00	6.9223334-02	7.9828834+00	
32	2.9907261+01	2.3849760+00	9.6261520-01	7.2294136+00	2.1392447-01	7.9464403+00	
33	2.9014527+01	2.4936320+00	9.6215954-01	7.2761469+00	4.1230860-01	7.8956735+00	
34	2.8126076+01	2.5992021+00	9.6161402-01	7.3318900+00	6.4241042-01	7.8359687+00	
35	2.7255616+01	2.6998324+00	9.6099662-01	7.3945486+00	8.9456972-01	7.7699341+00	
36	2.6409557+01	2.7947293+00	9.6032049-01	7.4627237+00	1.1626606+00	7.6993490+00	
37	2.5776019+01	2.8637691+00	9.5975894-01	7.5189779+00	1.3801166+00	7.6420722+00	

CHAR 40

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.	
35	3.8087907+01	2.8821015+00	9.6308672-01	7.1807683+00	.0000000+00	5.6540474-03	(MASS)
36	3.7866738+01	2.9099653+00	9.6308523-01	7.1809213+00	6.9508192-04	7.9998176+00	
37	3.7638563+01	2.9387074+00	9.6307939-01	7.1815258+00	3.4167785-03	7.9991482+00	
38	3.7415018+01	2.9668530+00	9.6306387-01	7.1831312+00	1.0662936-02	7.9973698+00	

WALL

POINT	X	Y	V/VMAX	MACH ANG.(D)	FLOW ANG.(D)	MACH NO.
1	3.8256243+00	8.1316152-01	8.9176088-01	1.3116391+01	1.1999999+01	4.4066463+00
2	3.9028480+00	8.2948851-01	8.9361103-01	1.2980792+01	1.1985932+01	4.4518761+00
3	3.9884616+00	8.4767910-01	8.9554486-01	1.2838727+01	1.1954040+01	4.5002969+00
4	4.0881107+00	8.6861997-01	8.9759003-01	1.2687724+01	1.1893385+01	4.5529632+00
5	4.2013489+00	8.9245296-01	8.9974194-01	1.2528317+01	1.1804278+01	4.6099496+00
6	4.3279902+00	9.1880974-01	9.0192807-01	1.2365398+01	1.1691594+01	4.6697230+00
7	4.7743664+00	1.0093134+00	9.0851001-01	1.1869951+01	1.1239442+01	4.8616621+00
8	5.2848142+00	1.1081824+00	9.1448422-01	1.1412522+01	1.0703148+01	5.0537828+00
9	5.8459027+00	1.2112328+00	9.1975869-01	1.1001535+01	1.0129364+01	5.2401212+00
10	6.4509450+00	1.3160605+00	9.2438556-01	1.0634692+01	9.5430785+00	5.4186893+00
11	7.0955232+00	1.4210430+00	9.2845033-01	1.0306948+01	8.9591629+00	5.5890429+00
12	7.7772609+00	1.5248919+00	9.3202331-01	1.0013970+01	8.3879515+00	5.7508191+00
13	8.4935469+00	1.6268757+00	9.3518756-01	9.7504176+00	7.8334778+00	5.9046984+00
14	9.2429228+00	1.7263847+00	9.3800468-01	9.5122350+00	7.2983610+00	6.0511369+00
15	1.0024924+01	1.8228512+00	9.4052538-01	9.2960002+00	6.7838965+00	6.1906122+00
16	1.0837733+01	1.9158960+00	9.4278459-01	9.0994562+00	6.2918856+00	6.3231641+00
17	1.1681002+01	2.0053718+00	9.4482981-01	8.9192575+00	5.8201414+00	6.4498477+00
18	1.2554288+01	2.0909696+00	9.4668635-01	8.7536567+00	5.3688166+00	6.5708876+00
19	1.3456948+01	2.1722430+00	9.4836411-01	8.6020721+00	4.9396966+00	6.6857844+00
20	1.4388335+01	2.2492799+00	9.4989600-01	8.4621174+00	4.5300646+00	6.7955349+00
21	1.5348071+01	2.3219389+00	9.5129722-01	8.3327252+00	4.1394422+00	6.9002954+00
22	1.6335940+01	2.3901015+00	9.5258158-01	8.2129060+00	3.7669889+00	7.0002593+00
23	1.7350810+01	2.4537253+00	9.5375942-01	8.1019504+00	3.4126530+00	7.0954745+00
24	1.8392607+01	2.5127527+00	9.5484168-01	7.9990546+00	3.0755510+00	7.1861413+00
25	1.9460904+01	2.5671639+00	9.5583754-01	7.9035483+00	2.7549951+00	7.2724168+00
26	2.0554839+01	2.6170049+00	9.5675445-01	7.8148945+00	2.4505334+00	7.3543963+00
27	2.1673861+01	2.6619384+00	9.5758938-01	7.7334514+00	2.1640706+00	7.4313683+00
28	2.2817857+01	2.7022260+00	9.5835639-01	7.6580869+00	1.8931440+00	7.5040596+00
29	2.3985211+01	2.7381109+00	9.5906083-01	7.5884135+00	1.6375394+00	7.5725495+00
30	2.5175799+01	2.7696705+00	9.5970842-01	7.5239741+00	1.3964291+00	7.6370273+00
31	2.6388666+01	2.7970057+00	9.6030186-01	7.4645778+00	1.1698309+00	7.6974472+00
32	2.7622181+01	2.8196726+00	9.6082805-01	7.4115368+00	9.6247003-01	7.7522240+00
33	2.8876467+01	2.8384740+00	9.6130731-01	7.3630182+00	7.6926053-01	7.8030229+00
34	3.0149464+01	2.8537166+00	9.6174238-01	7.3187933+00	5.9015381-01	7.8499146+00
35	3.1439634+01	2.8651689+00	9.6211983-01	7.2802321+00	4.3032438-01	7.8912677+00
36	3.2746722+01	2.8731220+00	9.6244384-01	7.2470034+00	2.8956927-01	7.9272550+00
37	3.4067759+01	2.8784281+00	9.6272034-01	7.2185772+00	1.6729090-01	7.9583061+00
38	3.5400733+01	2.8812342+00	9.6293503-01	7.1964347+00	7.0231895-02	7.9826629+00
39	3.6742769+01	2.8820118+00	9.6306360-01	7.1831581+00	1.0798387-02	7.9973404+00
40	3.8087907+01	2.8821015+00	9.6308672-01	7.1807683+00	.0000000+00	7.9999878+00

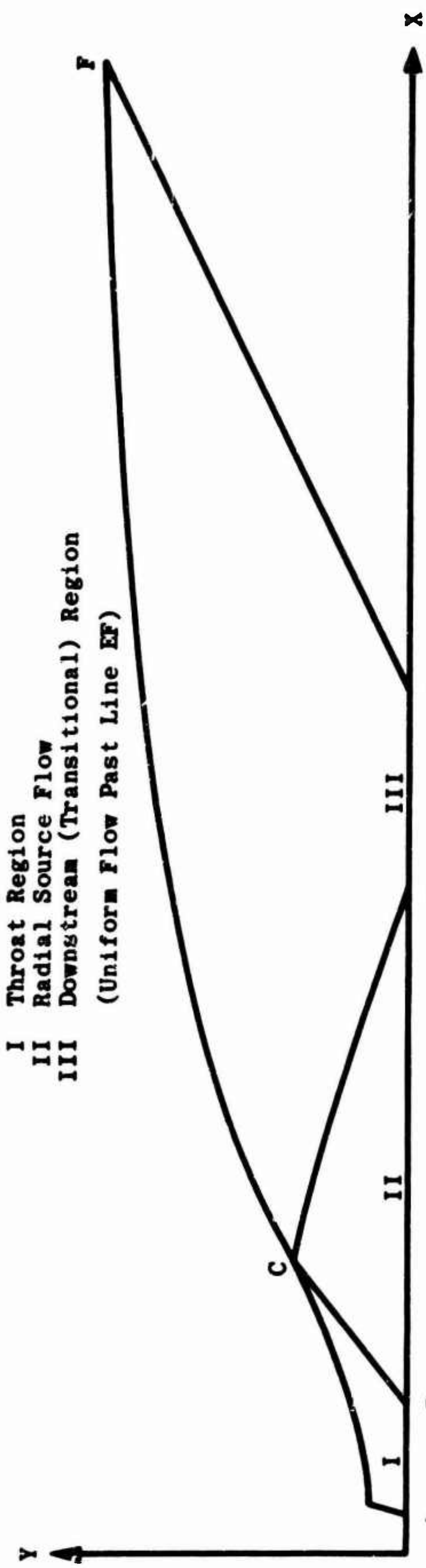


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Fig. 7 Nozzle Configuration (Not to Scale)

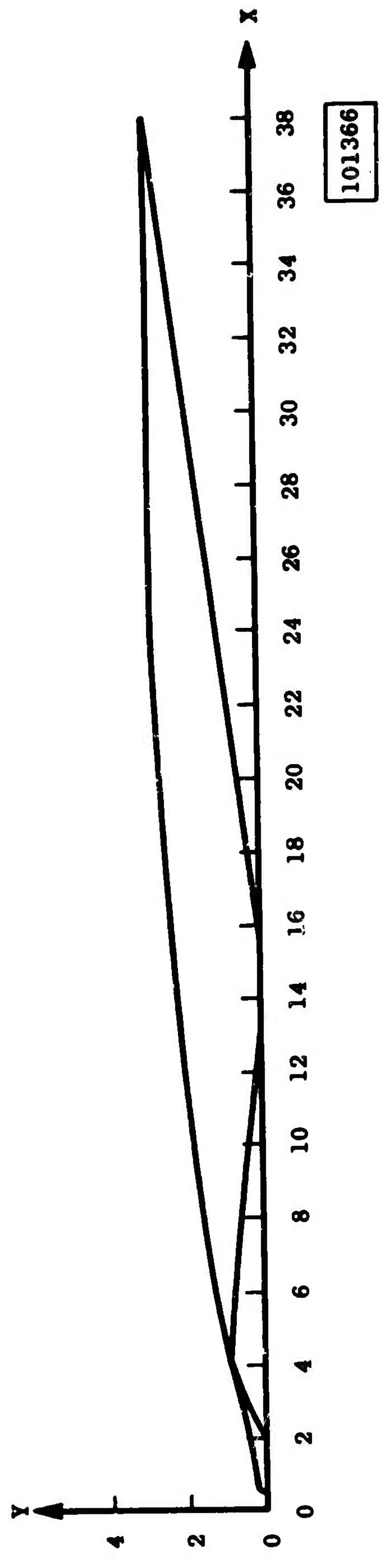

Fig. 8 Nozzle Configuration (to Scale)

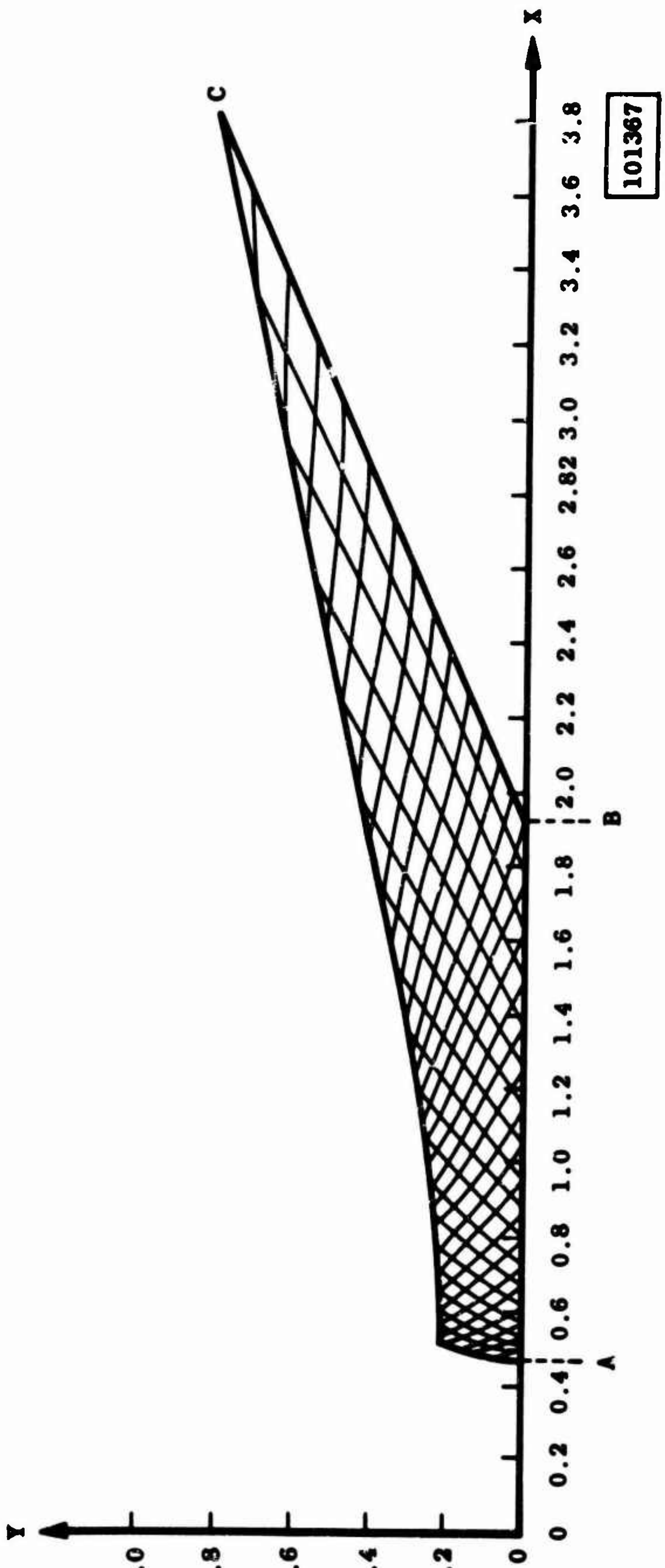

Fig. 9 Throat Region Showing Characteristic Network